

THE EFFECT OF NITROGEN FERTILIZATION
ON THE MOVEMENT OF NUTRIENTS FROM
A TROPICAL GRASS UNDER SOIL MOISTURE
STRESS IN A HOT SAVANNA

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TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	ii
LIST OF TABLES	vi
LIST OF FIGURES	ix
INTRODUCTION	1
REVIEW OF LITERATURE	3
The Tropical Grass	3
Savanna Soils and Their Fertility	4
Response of Tropical Grasses to Fertilization	6
Dry matter	6
Crude protein	9
Minerals	11
Fertilizer nitrogen recovery	12
Plant Metabolic Responses to Drought	13
Root growth	13
Nitrogen metabolism	15
Phosphorus metabolism	18
Tropical Forage Quality	18
Crude protein	18
Energy	20
Animal Performance in the Tropics	22
Voluntary intake	22
Weight gains	23
DESCRIPTION OF THE HOT SAVANNAS OF COSTA RICA	25
Climate	26
Geology	30
Soils	30
Vegetation and Agriculture	31
EXPERIMENTAL PROCEDURES	35
Selection of Site	35
Methods	35
Field experiments	35
Soil characterization	36

	Page
Physical Analysis	37
Chemical Analysis	38
Forage Cellulose Digestion	40
Statistical Analysis	41
RESULTS AND DISCUSSION	42
Soil Characterization	42
Field Experiment During the Dry Season	43
Dry matter	43
Nitrogen	46
Phosphorus	51
Field Experiment During the Rainy Season	58
Dry matter	58
Nitrogen	60
Forage Quality	63
Crude protein	63
Cellulose concentrations and <u>in vitro</u> cellulose digestion	66
Mineral composition	70
SUMMARY AND CONCLUSIONS	72
APPENDIX	78
LIST OF REFERENCES	107
BIOGRAPHICAL SKETCH	118

LIST OF TABLES

Table	Page
1. Monthly precipitation for the hot savanna region of Costa Rica	28
2. Extreme temperatures, relative humidity and sunshine hours for Cañas, L. P. Costa Rica, C. A.	29
3. Yields of oven-dry jaraguagrass forage during the dry season	44
4. Yields of oven-dry jaraguagrass roots during the dry season	45
5. Fertilizer nitrogen recovered in oven-dry jaraguagrass forage during the dry season	52
6. Yields of oven-dry jaraguagrass forage regrowth during the rainy season	59
7. Nitrogen concentrations in oven-dry jaraguagrass forage regrowth during the rainy season	61
8. Total nitrogen contents of oven-dry jaraguagrass forage regrowth during the rainy season	62
9. Crude protein concentrations in oven-dry jaraguagrass forage during the dry season	64
10. Total crude protein contents of oven-dry jaraguagrass forage during the dry season	65
11. Crude protein concentrations in oven-dry jaraguagrass forage regrowth during the rainy season	67
12. Cellulose concentrations and <u>in vitro</u> cellulose digestion of oven-dry jaraguagrass forage during the dry season	69
13. Profile descriptions of the soil of the experimental area	79

Table	Page
14. Physical properties of soils	80
15. Chemical properties of soils	81
16. Analysis of variance for yields of oven-dry jaraguagrass forage during the dry season	82
17. Nitrogen concentrations in oven-dry jaraguagrass forage during the dry season	83
18. Total nitrogen contents of oven-dry jaraguagrass forage during the dry season	84
19. Analysis of variance for nitrogen concentrations in oven-dry jaraguagrass forage during the dry season	85
20. Analysis of variance for total nitrogen contents of oven-dry jaraguagrass forage during the dry season	86
21. Nitrogen concentrations in oven-dry jaraguagrass roots during the dry season	87
22. Total nitrogen contents of oven-dry jaraguagrass roots during the dry season	88
23. Phosphorus concentrations in oven-dry jaraguagrass forage during the dry season	89
24. Analysis of variance for phosphorus concentrations in oven-dry jaraguagrass forage during the dry season	90
25. Total phosphorus contents of oven-dry jaraguagrass forage during the dry season	91
26. Analysis of variance for total phosphorus contents of oven-dry jaraguagrass forage during the dry season ..	92
27. Phosphorus concentrations in oven-dry jaraguagrass roots during the dry season	93
28. Total phosphorus contents of oven-dry jaraguagrass roots during the dry season	94
29. Analysis of variance for yields of oven-dry jaraguagrass forage during the rainy season	95
30. Analysis of variance for nitrogen concentrations in oven-dry jaraguagrass forage during the rainy season ...	96

Table	Page
31. Analysis of variance for total nitrogen contents of oven-dry jaraguagrass forage during the rainy season ...	97
32. Analysis of variance for cellulose concentrations in oven-dry jaraguagrass forage during the dry season	98
33. Analysis of variance for <u>in vitro</u> cellulose digestion of oven-dry jaraguagrass forage during the dry season	99
34. Potassium concentrations in oven-dry jaraguagrass forage during the dry season	100
35. Calcium concentrations in oven-dry jaraguagrass forage during the dry season	101
36. Magnesium concentrations in oven-dry jaraguagrass forage during the dry season	102
37. Phosphorus concentrations in oven-dry jaraguagrass forage regrowth during the rainy season	103
38. Potassium concentrations in oven-dry jaraguagrass forage regrowth during the rainy season	104
39. Calcium concentrations in oven-dry jaraguagrass forage regrowth during the rainy season	105
40. Magnesium concentrations in oven-dry jaraguagrass forage regrowth during the rainy season	106

LIST OF FIGURES

Figure	Page
1. Map of Costa Rica showing location of the Enrique Jimenez Nuñez Agricultural Experiment Station, Taboga, Guanacaste, and different weather stations in the Pacific "Tierra Caliente"	27
2. Effects of nitrogen fertilization and days of growth on the nitrogen concentrations in oven-dry jaraguagrass forage during the dry season	47
3. Effects of nitrogen fertilization and days of growth on the total nitrogen contents of oven-dry jaraguagrass forage during the dry season	48
4. Relationships between the total nitrogen contents of oven-dry jaraguagrass shoots and roots during the dry season	49
5. Effects of nitrogen fertilization and days of growth on the phosphorus concentrations in oven-dry jaraguagrass forage during the dry season	53
6. Effects of nitrogen fertilization and days of growth on the total phosphorus contents of oven-dry jaraguagrass forage during the dry season	55
7. Relationships between the nitrogen and phosphorus concentrations in oven-dry jaraguagrass forage during the dry season	56
8. Relationships between the total nitrogen and total phosphorus contents of oven-dry jaraguagrass forage during the dry season	57
9. <u>In vitro</u> cellulose digestion of oven-dry jaraguagrass forage at different fermentation periods	68

INTRODUCTION

The potential for cattle production in the tropics is probably greater than in other parts of the world. The availability of space, high radiation energy level, and good temperature throughout the year are environmental factors which are more favorable for forage growth in the tropics than in temperate climates. However, seasonal growth of pastures and fluctuations in their nutritive value, especially during long drought periods in the sub-humid, semi-arid and arid regions of the tropics, put a certain limitation on the improvement in the output of high quality forage to provide cattle feed above the maintenance requirements.

Tropical grasses are well adapted to their environment and their productivity and nutritive value can be improved by fertilization in most cases. Nitrogen (N) and phosphorus (P) are probably the most deficient elements in tropical grasslands. Forage concentrations of these elements are also critical in the nutritive value of the forage and animal performance. However, the total annual rainfall and its distribution pattern have a tremendous influence on the tropical environment which can affect pasture growth and composition, even at high levels of soil fertility. . There is a need for more information about the interaction of climatic and soil fertility factors in tropical environments in order to develop management practices to improve agricultural production and to increase food supply in the dry tropics.

The present investigation was designed to study the movement of nutrients from jaraguagrass (Hyparrhenia rufa (Nees) Stapf) as affected by nitrogen fertilization and soil moisture stress during the dry season in a hot savanna. The effects of harvest dates and residual nitrogen from the fertilizer applied at the end of the rainy season on forage regrowth after the dry season were also investigated. In addition, the nutritive value of the forage sampled during the dry and rainy seasons was evaluated in terms of crude protein, mineral composition, cellulose concentrations and in vitro cellulose digestion.

REVIEW OF LITERATURE

Davies and Skidmore (36) indicated that problems of grazing animals in the tropics arise from the fact that the field environment is difficult or sometimes impossible to change. They emphasized the importance of forage production in relation to seasonal growth of pastures, and to the nutrition and health of the grazing animals. Some tropical pasture species seem to be well adapted to extreme environmental conditions; however, their potential to supply adequate feed for cattle production may be limited not only by soil fertility but also by their mechanism of adaptation.

The Tropical Grass

Hyparrhenia rufa (Nees) Stapf has been described by Whyte, Moir and Cooper (132) as a densely tufted, perennial grass with basal leaves forming large tussocks when ungrazed. It is indigenous to tropical Africa where it is dominant over large areas particularly on heavy dark clay soil, under sub-humid and semi-arid conditions. They indicated that the grass is drought resistant but susceptible to frost. Saens-Maroto (101) indicated that the grass is known in Brazil by capim jaragua or jaragua, capim provisori, capim vermelho, sape gigantee, and pasto roxo; in Colombia by yaragua, yaragua or puntero and in Costa Rica by jaragua. McIlroy (74) refers to this grass in English as "jaragua grass."

Whyte et al. (132) mentioned that jaraguagrass was the most widespread pasture grass in tropical Central and South America. Boerendonk (10) reported this grass among the most common in the Cuban savannas. Kemp, MacKenzie and Romney (67) found the grass growing in British Honduras. Watkins and Chavez (127) recognized it as being important in infertile areas of El Salvador. Hogaboom (56) indicated its presence in Honduras. Taylor (114) said that jaraguagrass was among the main species of pasture grasses in Nicaragua. Rey-Gonzales and Mata-Pacheco (97) indicated that it is predominant in the Pacific lowland of Costa Rica. Ramia (96) and Fontana (46) in Venezuela, Espinal (41) in Colombia, Muro and Agreda (82) in Peru, Pastore and Thomson (88) in Paraguay and Braun (13) in Bolivia, indicated that jaraguagrass was an introduced forage species which occurs in those countries under dry tropical conditions. Jaraguagrass is very popular in the tropics because of its adaptation to dry conditions, resistance to fire, and good production of viable seed.

Savanna Soils and Their Fertility

Nye and Greenland (85) recognized in Africa the poor physical properties of soil developed under savanna as compared to forest. They reported that a typical analysis of savanna soil in Africa indicated nitrogen and phosphorus deficiencies and sometimes low exchangeable bases, although potassium rarely became deficient. The soil pH was usually above 5.0. Smith (106) mentioned that lack of nitrogen was the limiting factor in herbage production in Southern Rhodesia. Brockington (20) found that nitrogen was a serious limiting factor in plant growth on the reddish-brown clay soils of Central Africa. Phosphorus was also deficient but

potassium and calcium had little effect on growth of the Hyparrhenia dominant savanna.

Coaldrake (31) made the observation that the quantities of plant nitrogen in many of the natural tropical grasslands were large with little or no assistance from legumes. However, the concentration of nitrogen in the grass was not enough to support cattle production without the assistance of legumes or fertilizer nitrogen. Botha (11) explained that the increase in total soil nitrogen of the grass plot in his experiments with Eragrostis curvula Nees was due to non-symbiotic fixation of atmospheric nitrogen in the presence of readily oxidizable organic matter. Birch (7) indicated that the nitrogen availability in tropical soils in Africa depended on decomposition of organic matter. He observed that decomposition increased with air-drying of the soil. Hagenzieker (52) found in tropical Africa that there was an increase in mineral nitrogen at the beginning of the rainy season following a long dry season but it did not last more than 6 weeks. Greenland (49) reported that the period of most rapid nitrate increase in tropical soils was at the start of the rains following a dry season. However, Hardy (53) indicated that the fluctuation in soil nitrate between the wet and dry seasons was never very marked under pasture in tropical conditions. Theron (115) in Africa found that nitrification was entirely repressed under Hyparrhenia grass the second season after its establishment. This phenomenon was explained by Meiklejohn (76) in Ghana who said that "the most striking microbiological difference between forest and grassland soils is the lack of nitrite-oxidizing bacteria in grassland." However, Martin (72) indicated that nitrification might play a small role in the nitrogen nutrition of

permanent pastures in the tropics and that grasses can absorb this element almost entirely as ammonium. The potential for good pasture production in the tropics depends not only on the fertility of grassland soils but also on those factors affecting uptake and nutrient utilization by the forage plant throughout the year.

Response of Tropical Grasses to Fertilization

Dry matter

Walker (125) emphasized the high capacity of grasses to utilize nitrogen. The response of tropical grasses to nitrogen fertilization in terms of dry matter production was approximately linear to annual rates of 400 kg of the element per ha, provided that the moisture supply was adequate. Vicente-Chandler et al. (121) obtained annual yields of over 40,000 kg of good quality oven-dry forage per ha with heavy fertilization in the humid tropics of Puerto Rico. However, the yields were much lower in the semi-arid part of the country (119). Brockington (20) found that splitting the nitrogen fertilizer application, with the addition of superphosphate, resulted in linear yield response up to 200 kg nitrogen per ha per year with a Hyparrhenia dominant grassland in Northern Rhodesia. However, Smith (107) working in the same Hyparrhenia veld found no advantage in splitting the fertilizer in the first two years of application. All the fertilizer was applied at the start of the rainy season. Noland, Broce and Vergara (84) reported that the dry matter yield of jaraguagrass increased 70% by application of 800 kg per ha of a 10-30-10 fertilizer at the beginning of the rainy season. They increased yields of jaraguagrass in Panama by 58% with the application of about

200 kg nitrogen per ha.

Burgos¹, working with two dark clay soils from a savanna of the interior of Honduras, reported that those soils did not respond to nitrogen fertilization until a sufficient supply of phosphorus was available to the plants. Blue², working with tropical grasses at Liberia, Costa Rica, reported good response to the application of nitrogen and phosphorus. Yields increased linearly with applications to 60 kg of nitrogen per ha per harvest; excellent yield response was obtained with application of 30 kg phosphorus per ha, but no response to potassium was obtained.

It is possible to fertilize the grass before the dry season and insure adequate moisture for forage growth. This forage could be harvested for hay or for "deferred grazing" during the dry season. Russell (100) recommended application of nitrogen to grasses at the very end of the rainy season to raise the protein concentrations of the dry season growth. He also indicated that standing dry fodder will have a higher protein content. Andrade et al. (2) indicated that for the savanna region of Costa Rica the fertilizer should be applied during the first half of October. Blue² reported results from field experiments on the effect of fertilizer applied at the end of the rainy season on forage yields of three tropical grasses left standing in the field for dry season grazing. These experiments were conducted in the hot savanna of Costa Rica. The fertilization consisted of 55 kg nitrogen per ha with phosphate

¹Burgos, C. F. 1967. Nitrogen-phosphorus interaction in two dark clay soils from Honduras. Ph.D. Thesis. University of Florida, Gainesville.

²Blue, W. G. 1960. Fertilization experiments with grass pastures in Costa Rica. Final report of assignment to Costa Rica under the University of Florida/STICA contract. University of Florida, Gainesville.

and potash to give a 2-1-1 ratio, and the samples were taken on December 18. In general, the areas fertilized on October 1 gave higher forage yields compared to no fertilization. Jaraguagrass and buffelgrass (Cenchrus ciliaris L.) produced 6,068 and 4,709 kg oven-dry forage per ha with fertilization compared to 4,582 and 3,309 kg per ha, respectively, Argentine bahiagrass (Paspalum notatum Flugge) produced lower yields compared to the other two grasses. He reported, in another experiment designed to determine the effect of rates of nitrogen fertilization and the dry season on yields of forage left standing in the field for dry season grazing, that jaraguagrass yields harvested on December 18 increased from 4,486 to 6,468 kg oven-dry forage per ha for the 41 kg nitrogen per ha treatment. Subsequent harvests on January 26 and March 11 showed little change in forage yields. Blue² also reported a significant interaction between the days of growth and nitrogen treatments.

Brockington (21), working with several tropical grasses in Northern Rhodesia, found little response to complete fertilization with nitrogen, phosphorus and potassium during the dry season. The highest total dry matter production for the dry season was 2,500 and 2,135 kg per ha for Eragrostis curvula Ness and Cynodon plectostachyus (K. Schum) Piler, at the hay stage, respectively. Yields as low as 396 kg dry matter per ha were obtained with Chloris gayana Kunth at the same stage of growth. The yields were consistently smaller for all the grasses harvested at grazing stage, which emphasized leaf production. The lower yields obtained in Northern Rhodesia compared with those obtained in Costa Rica were probably due to less water available for forage growth at the beginning of the dry season.

Crude protein

The tropical grass species discussed by Oyenuga (87) were low in crude protein when compared with temperate grasses at similar stages of growth. However, Schofield (102) found marked differences in protein concentrations between various tropical species under the same soil-climatic conditions in Queensland, Australia. He reported that the crude forage protein varied from 5.2 to 14.9%, on the dry-weight basis. Cartmill (27) indicated that the crude protein of native grass in Queensland, Australia ranged from 8.8 to 13.0% when samples representing the part actually ingested by the ruminant were obtained.

Edward and Bogdan (40) found that the crude protein concentrations of jaraguagrass in Kenya was 14.3% after three weeks of growth. They pointed out that, at this stage, the dry matter produced would be insufficient for grazing or cutting. Jardim et al. (62) reported that the crude protein content of jaraguagrass in Brazil was as high as 11.8% at the end of the rainy season. French and Chaparro (44) found that the crude protein content of jaraguagrass in Venezuela varied from 1.4 to 7.3% during the dry season. Watkins and Levy-van Severen (128) mentioned that the average crude protein of jaraguagrass cut every three months throughout the year was 3.9%. They also indicated that this grass had the lowest crude protein of all tropical species examined. Miller, Rains and Thorpe (80) also found that the crude protein concentration of jaraguagrass was lower than any other grass silage in Northern Nigeria. Brendon and Horrell (16) reported similar results from Uganda.

It is possible to increase the crude protein concentrations of tropical forage by nitrogen fertilization, provided that water is not a

limiting factor. Vicente-Chandler, Silva and Figarella (120) found that the protein concentrations and contents of Guineagrass (Panicum maximum Jacq.) in Puerto Rico increased with nitrogen applications to 1,790 kg per ha divided into several applications throughout the year. The crude protein of the grass averaged 9.6%. Caro-Costas, Vicente-Chandler and Figarella (24) later reported average crude protein concentrations of heavily fertilized grass in Puerto Rico as high as 18.1%. Both experiments were conducted in the humid region of Puerto Rico. Pedreira et al. (90) found that the crude protein of jaraguagrass in Brazil increased from 7.7 to 9.4% when fertilized with nitrogen, phosphorus, potassium and micro-nutrients, after application of lime. Blue² reported that the crude protein of jaraguagrass in the hot savanna of Costa Rica increased to 9.5% during the rainy season with application of 210 kg nitrogen per ha and to 9.4% when fertilized with 120 kg nitrogen per ha at the end of dry season. However, the effect of nitrogen fertilization on crude protein concentrations of the forage did not last beyond the middle of the dry season.

The protein concentrations of tropical grasses follow a marked seasonal pattern tending to decrease during the dry season, regardless of nitrogen fertilization. Brendon and Horrell (15) indicated that all the grasses studied in Uganda showed a considerable decrease in the protein from the beginning of the rains to the end of the dry season. Lansbury, Innes and Mabey (69) found that the protein concentrations of grass in Ghana fell from 13.0% after the first rains to 3.4% during the dry season. They also indicated that the protein concentrations

of herbage decreased rapidly as the plant matured; however, the total of protein content did not decrease in any case. Todd (116) reported that the crude protein in grasses in Kenya decreased from 15 to 20% at the beginning of the rainy season to 4 to 5% during the dry season. Oyenuga (87) observed that the decrease in the crude protein concentrations of the forage was more marked in some tropical grass species than in others. Pennisetum purpureum Schumacher appeared to contain more protein than any other grass observed in Nigeria.

Weinmann (129), working with Chloris gayana Kunth, a tropical grass, found that considerable amounts of nitrogen, phosphorus and potassium were lost from the shoots after flowering and seed formation. He worked with pots and was able to recover large amounts of these elements in the roots. He explained that in addition to translocation from shoots, nitrogen and mineral elements also accumulated in the roots to a certain extent by simultaneous absorption from the soil.

Andrade et al. (2) working with jaraguagrass under field conditions in the savanna region of Costa Rica found that protein declined in the forage during the dry season. They indicated that since there was no rain to have leached protein from the leaves and no appreciable loss of leaves from the plant took place, nitrogen must have been translocated to the roots under the unfavorable growth conditions of soil moisture stress. However, they did not present root data to support their suggestion of nitrogen translocation.

Minerals

The mineral concentration of tropical grass varies with the species and mineral content of the soil. In general, phosphorus is low for most

of the tropical region of the world. Schofield (103) reported forage concentrations between 0.09 and 0.34% phosphorus in tropical Australia. The calcium concentrations of the grasses varied from 0.22 to 0.50% in the same region. Howard and Burdin (59) found that in Kenya the phosphorus levels of grasses varied from 0.07 to 0.25%; calcium levels between 0.30 and 0.61%; magnesium approximately 0.18%; and potassium varied from 0.98 to 3.12%, on the oven-dry basis. They also reported significant correlations between the crude protein and minerals, except for calcium. French and Chaparro (44) indicated that the phosphorus concentrations of jaraguagrass during the dry season in Venezuela varied from 0.02 to 0.11%, calcium from 0.27 to 0.42%, potassium 0.22 to 0.87% and magnesium 0.17 to 0.46%. There was no apparent correlation between crude protein and minerals. Jones (63) presented data for the mineral concentration in several grasses from a Hyparrhenia dominant grassland in Northern Rhodesia. Phosphorus varied from 0.06 to 0.21%, calcium from 0.23 to 0.63%, potassium from 0.53 to 2.25% and magnesium from 0.07 to 0.27%, from growth throughout the year. He also showed figures for sodium, sulfur and chlorine. The phosphorus and potassium contents of cultivated grasses grown in the same region were low for the dry season and similar to the unfertilized native grass (Jones (64)).

Awan (4) in Honduras reported an increase in the phosphorus concentration of jaraguagrass from 0.15 to 0.39% with application of 35 kg phosphorus per ha at the beginning of the rainy season.

Fertilizer nitrogen recovery

Martin and Skyring (73) pointed out that the recoveries of fertilizer nitrogen from growing crops seldom exceeded 50%. Furthermore, the

succeeding crops usually do not utilize more than an additional 10%. The residual nitrogen may be immobilized in the organic form or lost by leaching, erosion of volatilization. Henzell (55) said that a nitrogen recovery of 50 to 75% could be regarded as very satisfactory for grasses. He mentioned that the range for tropical conditions was from 10 to 88%. Blue et al. (9) reported a recovery of more than 100% with pangolagrass (Digitaria decumbens Stent) from the humid region of Costa Rica. However, the recovery with elephantgrass (Pennisetum purpureum Schumach) was about 10%. They could not find any explanation for this difference other than differences in species and growth habit. Smith (105) found that the recovery with Hyparrhenia veld was about 40% in Northern Rhodesia. Dilz and Woldendorp (38), working with ^{15}N concluded that under field conditions a substantial part of the fertilizer nitrogen may be tied up in the organic nitrogen cycle in roots and soil.

Plant Metabolic Responses to Droughts

The first effect at the beginning of the drought is decreased photosynthesis associated with increased respiration. The decrease in photosynthesis, according to Levitt (70), is due to stomatal closure and decrease in the rate of diffusion of carbon dioxide through the dry mesophyll of the leaf. Since photosynthesis decreases, respiration tends to increase to maintain the energy balance of plant metabolism.

Root growth

Root growth is favored more than shoot growth when the soil becomes drier, and the first effect of the drought is an increase in the root: shoot ratio. Troughton (118) indicated that the changes in the

environment may be interpreted as tending to maintain a balance between the photosynthesis in the shoots and the activity of the roots. Oppenheimer (86) reported that the root: shoot length relations were 3.5:1 to 6.0:1 in xerophytic grasses compared to less than 3.0:1 in the more mesophytic ones. This response is probably due to the fact that the carbohydrate reserves of the plant, which are the source of energy and metabolic water during respiration, are greater in the roots compared to the shoots. Soil aeration, temperature and availability of moisture at the deeper horizons will also influence root growth. However, root distribution studies indicate that the majority of grass roots occur in the upper layer of soil. Gwynne (51) indicated that pangolagrass had more than 75% of its roots, on a dry-weight basis, concentrated in the top 30 cm of soil, while corn had 98% and sugar cane over 85% in the top 61 cm of soil.

The absorption of nutrients by the roots is affected by soil moisture. Volk (123) found increases in nitrogen and potassium intake with plants growing in soil at below the wilting point. There was very little increase in phosphorus intake. Stocker (113) indicated that in general, plants grown under dry conditions showed an increase in nitrogen uptake and a decrease in potassium uptake. The data for phosphorus, calcium and magnesium are not sufficiently clear to draw conclusions. However, Gates (47) reported that during wilting the uptake of nitrogen and phosphorus by tomato plants was noticeably reduced. Wilting depressed phosphorus concentration more than nitrogen. Williams (133) found no fundamental physiological difference between the seminal and adventitious root system grasses. He pointed out that translocation of nutrients from the roots

ceases when flowering occurs. The increase in weight of roots growing under soil moisture stress compared to shoots can be explained, in part, by the increase in nutrient absorption from the soil and diminished nutrient translocation to the shoots. However, it does not mean that nutrients from the shoots can not be translocated back to the roots when environmental conditions are unfavorable for shoot growth.

Weinmann (130) mentioned that the fertilizer nitrogen stimulated top growth more than root growth in forage plants. However, Troughton (117) indicated that it appeared that plants grown in conditions of low available nitrogen had well-developed root systems compared to shoot growth. Weinmann (131) found later that the nitrogen content of roots was higher when nitrogen was applied.

It is possible that the root growth in response to fertilizer will have a maximum determined by the physical characteristics of the soil. Holt and Fisher (57) reported that under high nitrogen fertilization the accumulation of roots remained at a fairly constant level while forage production increased in response to the fertilizer.

Nitrogen metabolism

Hegarty (54) mentioned in 1962 that there was little information available on the effect of the tropical environment on the metabolic processes of tropical grasses. However, information available about effect of drought on plant metabolism from other regions can be useful in tropical conditions, provided that low temperature is not a factor.

Petri and Wood (92) working with two grasses, Phalaris tuberosa L. and Lolium multiflorum Lam. suggested that the net rate of protein formation from amino acids decreased with reduction of water content in the

leaf. They also mentioned (93) that decreasing water content could lead to protein hydrolysis and decrease protein synthesis in the leaves. Stocker (113) explained that hydration stabilizes the existing protein structure. The protoplasmic structural changes during the drying of the environment are due to shrinking of hydrophylic groups of protein molecules which leads to mechanical tensions and exposure of bonds. This results in breaking of bonds, and tearing and loosening of the structure. He mentioned that this phenomenon usually occurs between 30 and 40% of the field capacity of the soil, depending upon the rate of drying. The proteolysis of the leaf protein leads to an increase of soluble nitrogen compounds of low molecular weight which can migrate to the more metabolically active parts of the plant. McKee (75) indicated that protein in older leaves of annual plants is hydrolysed and the products are translocated to other parts of the plant. Chen, Kessler and Monselise (30) found that the total nitrogen level in the upper parts of citrus seedlings increased at the same time that it decreased in the roots during the period of water stress. These reports seem to indicate a different pattern for movement of nitrogen during water stress on annual and perennial plants. A different pattern of movement between dicotyledons and grasses is also possible.

Kemble and Macpherson (66) working with perennial ryegrass (Lolium perenne L.) found that all the nitrogen from the degraded protein reappeared as α amino acids, volatile base amides or peptides upon wilting after cutting. Barnett and Naylor (5) reported that amino acids were synthesized in bermudagrass (Cynodon dactylon (L.) Pers.) during water stress but at the same time protein synthesis was inhibited and protein levels

decreased. They also found accumulations of free proline and free asparagine, increases in levels of valine and glutamic acid and a decrease in alanine levels in the shoots. However, they did not discuss the movement of these compounds from the shoots to the roots.

Shah and Loomis (104) found that the relative concentration of RNA and protein decreased in sugar beets (Beta vulgaris) as the stress condition developed during drought. Kessler (68) reported an initial rise in RNA content in higher plants followed by a decrease over a period of drought. DNA synthesis was also diminished. He explained that the protein hydrolysis during wilting was the result of decrease in RNA content. There is little information about the role of RNA on maintenance of protein structure during wilting and any effect on protein synthesis may be reflected by the accumulation of amino acids and peptides. This accumulation could be interpreted as the result of protein hydrolysis.

The metabolism of nitrogen in the plant could result in losses by volatilization, leaching or excretion through the roots. Pearsall and Billimoria (89) reported nitrogen volatilization from leaves floating on nutrient media with nitrates. No losses were observed when organic sources of nitrogen were used. However, Allison et al. (1) found no significant gaseous losses from leaves under any condition when organic and inorganic sources of nitrogen were used. Viets (122) indicated the possibility of nitrogen losses by volatilization from plants. However, he mentioned that nitrogen losses from the plant by leaching were not generally regarded as significant. McKee (75) suggested excretion of nitrogenous substances through the roots as a possibility for losses from green plants. Katnelson, Rouatt and Payne (65) reported that it was the

case with cereals grown on sterile sand-soil mixture. In any case the nitrogen losses from the plants by different mechanisms were not sufficient to affect the total nitrogen content of the plant.

Phosphorus metabolism

Phosphorus and nitrogen metabolism in plants are closely associated and Stocker (113) indicated that changes in the metabolism of one of these elements will also affect the other. Weinmann (131) concluded that nitrogen and phosphorus were translocated from the shoots to the roots of grasses under unfavorable growth conditions. However, he did not show a direct relationship between the movement of these two elements. Andrade et al. (2), working in the savanna region of Costa Rica, did not present data on the phosphorus status of jaraguagrass during the dry season.

Tropical Forage Quality

Milford and Minson (78) stated that the feeding value of a forage plant is determined by the quantity of dry matter produced. The nutritive value of the forage is largely determined by the crude protein and energy contents. The mineral composition and vitamin supplies are also important, especially under grazing, but these components can be supplied so easily that little attention is given to them unless deficiencies appear in the cattle. However, the best indication of the relative nutritive value of a forage is animal performance.

Crude protein

Glover, Duthie and French (48) suggested that the total crude protein concentration in the feed, irrespective of its nature, determines the

digestibility of the protein by ruminants. They based this observation on analysis of the results presented on 597 records of digestibility trials of herbage and mixed feeds with cattle and sheep of different breeds in many parts of the world, including the tropics. There is a direct relationship between the crude protein concentration in the forage and the apparent digestible crude protein by ruminants as indicated by the following equations calculated with digestibility trial data for temperate and tropical grasses.

$$\begin{array}{llll} \text{DCP} = 0.959\text{CP} - 3.55 & r = 0.992^{**} & \text{Brendon, Harker and Marshall (17)} \\ \text{DCP} = 0.899\text{CP} - 3.25 & r = 0.979^{**} & \text{Milford and Minson (77)} \\ \text{DCP} = 0.929\text{CP} - 3.48 & r = 0.995^{**} & \text{Holter and Reid (58)} \end{array}$$

where:

DCP = apparent digestible protein
CP = crude protein concentrations
** = significant at the 1% level.

These three equations are similar and the correlation coefficients are highly significant regardless of the type of animal and feed used in the digestibility trials. These equations suggest a critical value of about 3.6% crude protein in the forage; below this value the apparent digestible crude protein is essentially negative for practical purposes. The optimum levels of crude protein for normal growth of cattle are 9 to 11% which will result in 5.6 to 7.5% digestible protein according to the National Research Council (50). French, Glover and Duthie (45) indicated that these general equations could be used in the tropics to compute maintenance and production rations for meat and milk. They also indicated that the standard procedure for determination of digestible crude protein is time consuming and not suited to the rapid change in chemical composition of herbage under dry tropical conditions.

Crude protein concentration of the forage may have an effect on forage intake; however, Milford and Minson (78) reported that crude protein of tropical grasses had no effect on forage intake if it were above 7%. A decline in intake occurred below that level. Bedrak et al. (6) reported that heifers fed protein deficient rations showed decreased appetite, lower rate of gain, lower rate of reproduction, and lower hemoglobin and hematocrit blood values, compared with those fed adequate protein levels. The levels of crude protein in the grass for animal production in the tropics is extremely important since cattle obtain most of their nutrients from forage under grazing.

Energy

Organic matter digestibility is the method most widely used for comparing the nutritive values of the energy in tropical forages. Milford and Minson (78) pointed out that there are no figures available for net energy values of tropical pastures. However, Moir (81) reported that the correlation between digestible energy concentration and dry matter digestibility of forage in Australia was highly significant. Butterworth (22) indicated the same relationship for some tropical forages in Trinidad. Both authors calculated equations as follow:

$$\begin{array}{ll} Y = 0.0467X - 0.192 & \text{Moir (81)} \\ Y = 0.0418X + 0.219 & \text{Butterworth (22)} \end{array}$$

where:

Y = digestible energy in kcal per g
X = coefficient of organic matter digestibility.

Naga and el-Shazly (83) found a highly significant correlation between in vivo and in vitro cellulose digestion for grasses but not for

legumes in Egypt. They reported highly significant correlations for grasses only between in vivo cellulose digestion and digestible energy, and between the in vitro cellulose digestion and digestible energy. In vitro cellulose digestion is a good measure of the energy value of forage grasses because of the general simplicity of the method and small weight of sample involved. It can be very useful in pasture programs to evaluate forage species and management, although the interpretation of the results can be misleading if other factors, such as voluntary intake by the animals, are not taken into consideration.

French (43) found that the dry matter digestibility coefficient of several species ranged between 51.1 and 72.8% depending on stage of growth. Marshall and Long (71) indicated that the dry matter digestibility coefficient of some East African grass hays varied between 45.6 and 70.6%, depending on the species. Both reports were based on digestibility trials. Da Silva, Conrad and Campos (35) mentioned that the in vitro cellulose digestion of some forage plants in Brazil decreased from 88% to 72% as the cellulose concentration increased from 32.8 to 39.3%. Their results were based on 48-hr fermentations and seem to be relatively high compared to the results of digestion trials mentioned above.

Smith (106) indicated that the digestibility of organic matter in a Hyparrhenia veld in Africa declined from 50 to 38% as the grass matured; fertilization increased digestibility by 10%. Jardim (61) reported from Brazil that the digestibility of jaraguagrass decreased from 56.6% at a young stage to 42.7% after flowering. However, Miller and Rains (79) found that in Nigeria the digestibility of jaraguagrass determined at

preflowering stage, in the middle of the rainy season, was only 39.6%. This value was lower than that of any other grass studied. Butterworth (22) studied the digestible energy content of some tropical forages in Trinidad using sheep and a bomb calorimeter to determine energy values of feeds and feces. He found that gross energy varied from 4.13 to 5.02 kcal per g dry matter and digestible energy varied from 2.23 to 3.20 kcal per g dry matter. Marshall and Long (71) reported in similar studies in Africa that the gross energy of tropical pastures was between 4.02 and 4.21 kcal per g dry matter and the digestible energy varied from 1.90 to 2.99 kcal per g. The energy value of jaraguagrass was lower than any other grass studied, in both cases. The low energy value of jaraguagrass can be compensated by the amounts of forage produced which could increase carrying capacity and weight gains per unit area.

Animal Performance in the Tropics

Voluntary intake

The feed consumption by cattle is limited by voluntary intake, provided that sufficient forage is available. Miller and Rains (79) reported that the relative intake of tropical forages in Nigeria averaged 1.5 kg of dry matter per 100 kg of body weight for cattle and 1.9 for sheep. However, the difference in intake did not take into consideration animal size. Milford and Minson (78) indicated that this can be corrected by expressing the results on the basis of unit metabolic size in terms of intake per $\text{kg}^{0.73}$ of live weight. They showed that the intake of tropical grasses varied with species and stage of maturity, and forage intake in Australia ranged from 22 to 92 g per $\text{kg}^{0.73}$ live weight per day.

Weight gains

There are few reports of grazing trials in the tropics which indicate seasonal variations in the weight gains of cattle and performance with different grass species. Carrera and Ferrer (26) reported that the weight gains of Zebu animals in grazing trials with jaraguagrass in Mexico averaged 185 to 199 kg per ha per year over a two-year period. Carrera (25) indicated later that the steers grazing jaraguagrass showed the smaller rate of daily gain, 248 g compared to 550 g for pangolagrass, over a three-year period. Arroyo and Teunissen (3), working with Zebu steers in a put and take grazing trial in Mexico, found that the gains in weight from July to January varied with the forage species. The gains with jaraguagrass were 190 kg per ha, compared to 150 and 406 kg per ha for guineagrass and pangolagrass, respectively. Carneiro et al. (23) in Brazil pointed out that the average daily weight gain per animal was 282 g for the dry season compared to 528 g during the rainy season. The animals were on jaraguagrass pastures in both seasons but received some additional feed during the dry season.

Fertilization can influence animal performance in the tropics; however, it seems that seasonal variations prevail under all circumstances. Quinn et al. (95) reported that the daily weight gain of Zebu steers in central Brazil varied from 77 to 175 g with fertilized grasses compared to 4 to 40 g without fertilizer during the dry season. For the rainy season the variation was from 570 to 813 g with fertilization compared to 588 to 804 g without fertilization. They indicated that, combining the results for both seasons, the live weight gains per unit area for animals grazing on jaraguagrass were greater than any other grass with or without

fertilization. With fertilization the jaraguagrass produced 448 kg of live weight gain per ha and 249 without fertilization. However, the gains during the dry season were 5.7 and 0.3% of those during the rainy season with and without fertilization, respectively.

The inclusion of a legume in a grass sward can also influence animal performance under grazing in the tropics, but again the season of the year can be a limiting factor. Stobbs(111) found that the inclusion of Stilosanthes gracilis or Centrocema pubescens with three tropical grasses including jaraguagrass, increased annual live weight gains of Zebu cattle by 14 to 41%. They stressed the value of the legume during the dry season which increased live weight from about 188 to about 470 kg per ha per year. Stobbs and Joblin (112) indicated later that the live weight gain of Zebu cattle in Africa increased from 289 to 401 kg per ha during the dry season and from 1599 to 1823 kg per ha during the rainy season when Centrocema pubescens was included with jaraguagrass pastures under grazing conditions. These reports seem to indicate that protein was probably the limiting factor for cattle performance and the legumes were able to provide it, even though there was a limitation in the availability of water during the dry season.

DESCRIPTION OF THE HOT SAVANNAS OF COSTA RICA

The lowland savannas of Costa Rica are located in the northwest section of the country between latitude $10^{\circ} 00'$ and $11^{\circ} 00'$ N and longitude $84^{\circ} 30'$ and $86^{\circ} 00'$ W, extending toward the southwest part of Nicaragua, Central America. It includes most of the Guanacaste Province and part of Puntarenas Province.

The region can be divided for descriptive purpose into the following distinctive physiographic areas, according to a geodetic survey prepared by the U. S. Army.³

(a) Mainland.- It lies north, northwest and southeast of the Tempisque Valley and consist of a gently sloping piedmont leading to steep slopes of high volcanic mountains in the Cordillera Guanacaste.

(b) Tempisque Valley.- It is located northwest of the Gulf of Nicoya. It consists of a gently sloping, alluvial-filled depression about 60 km long and 20 km wide, less than 50 m above sea level.

(c) Nicoya Peninsula.- This area is physiographically separated from the mainland by the Tempisque Valley and is maturely dissected into sharp ridges, peaks and V-shaped canyons with small coastal plains and narrow stream valleys.

³Costa Rica. 1965. Recommendations on natural resources studies for development of Nicoya-Tempisque Region, Costa Rica. Report prepared for U.S.A.AID/Costa Rica by U. S. Army, Inter American Geodetic Survey. Natural Resources Division. Fort Clayton, Canal Zone. 14 p.

Climate

The climate of the hot savanna region of Costa Rica is characterized by two distinctly divided seasons, rainy and dry. About 90% of the annual precipitation, 1400 to 2400 mm, falls during the rainy season, from May through November. Rainfall data for different weather stations in the region shown in Fig. 1 are presented in Table 1. Cañas, Cañas La Pacífica and Liberia are located in the Tespisque Valley, Esparta is located on the mainland and Santa Cruz is located on the Nicoya Peninsula.

The records suggest two maxima during the rainy season, one in June and another in September, and a very dry season from December through April.

Extreme temperatures, relative humidity and daily sunshine hours for the weather station Cañas La Pacífica in Guanacaste Province are shown in Table 2. The average maximum temperature, 35.5 C, and the average minimum temperature, 21.0 C, fluctuate little during the year and do not seem to be influenced by the rainfall to any great extent. However, the temperatures are modified by elevation.

The relative humidity is high throughout the year with an average maximum around 95% and a minimum around 55%, reaching maxima of 100% during the rainy season. The average daily sunshine hours are around 6; however, less sunshine occurs during the rainy season due to heavy cloud cover.

The climate of this region is typical of the hot savannas of Latin America which include the Bolivar savannas of Colombia, "Llanos" of Venezuela and Colombia, savannas of the Amazon basin and Guyana, savannas of Bolivia, Mato Grosso and the Gran Chaco, and the Cuban savannas,

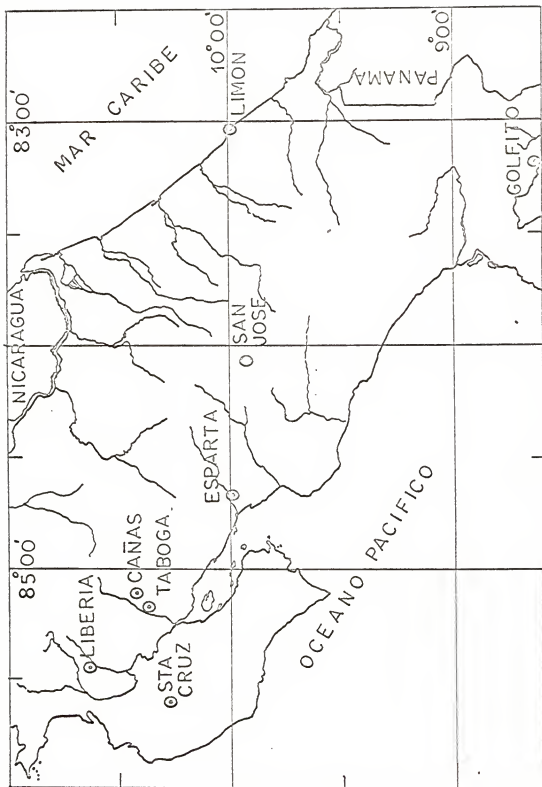


Fig. 1. Map of Costa Rica showing location of the Enrique Jimenez Nunez Agricultural Experiment Station, Taboga, Guanacaste, and different weather stations in the Pacific "Tierra Caliente."

Table 1.- Monthly precipitation for the hot savanna region of Costa Rica, C. A.¹

Month	Weather stations					Monthly Avg
	Cañas ² 1961-66	Cañas, L.P. ³ 1951-66	Liberia ⁴ 1951-66	Esparta ⁵ 1951-65	St. Cruz ⁶ 1951-65	
	----- mm -----					
Jan.	0.5	6.5	0.6	4.0	2.2	2.7
Feb.	0.3	16.9	0.1	6.6	3.8	5.5
Mar.	7.6	2.6	1.6	1.1	0.8	2.7
Apr.	24.6	37.0	16.1	52.2	12.6	28.5
May	111.6	208.9	226.3	268.9	260.7	215.3
Jun.	322.0	294.6	282.1	324.1	321.1	308.8
Jul.	167.2	166.1	205.2	345.2	247.3	226.2
Aug.	128.2	193.5	150.9	305.6	177.7	191.2
Sept.	293.3	328.1	356.3	344.0	361.5	336.6
Oct.	237.4	365.6	326.2	462.1	422.6	362.8
Nov.	107.4	80.6	89.5	171.1	98.7	109.4
Dec.	5.5	7.4	4.3	24.5	21.9	12.7
Total	1,405.6	1,707.8	1,659.2	2,309.4	1,930.9	1,802.6

¹Servicio Metereológico Nacional, Ministerio de Agricultura y Ganadería, San José.

²Guanacaste 10° 25' N 85° 07' W, altitude 95 m.

³La Pacífica, Gte. 10° 28' N 85° 09' W, altitude 45 m.

⁴Guanacaste 10° 37' N 85° 26' W, altitude 144 m.

⁵Puntarenas 9° 59' N 84° 40' W, altitude 225 m.

⁶Guanacaste 10° 16' N 85° 37' W, altitude 50 m.

Table 2.- Extreme temperatures, relative humidity and sunshine hours for Canas, L.P.,¹ Costa Rica, C. A.²

Month	<u>Extreme temperatures</u>		<u>Relative humidity</u>		<u>Daily sunshine hours</u>		
	Max.	Min.	Max.	Min.	1964	1965	1966
	----- C -----		----- % -----		----- hr : min -----		
Jan.	36.2	21.5	84	56	9:24	6:42	8:12
Feb.	35.7	21.2	83	49	9:36	----	8:48
Mar.	35.5	23.0	86	50	8:00	9:54	8:48
Apr.	37.0	22.2	82	44	8:00	8:18	8:48
May.	38.0	21.5	90	47	5:24	6:42	5:06
Jun.	35.3	20.5	97	59	4:24	5:42	3:00
Jul.	34.6	21.0	97	62	5:00	4:48	5:12
Aug.	34.8	20.5	98	57	4:18	5:18	5:36
Sept.	35.3	20.5	100	59	4:24	5:06	4:42
Oct.	35.1	19.8	98	61	3:36	5:24	4:00
Nov.	34.8	19.6	94	58	5:36	5:42	6:54
Dec.	34.0	21.5	92	56	8:06	7:06	5:06
Avg	35.5	21.0	92	55	6:19	5:30	5:30

¹La Pacifica, Gte. 10° 28' N 85° 09' W, altitude 45 m.

²Servicio Meteorológico Nacional, Ministerio de Agricultura y Ganadería, San José.

according to Roseveare (99). However, the Cuban savannas should not be included in this group because of the temperature influence due to large cold fronts which occasionally come from the north during the dry season.

Geology

The geology of this region has been described in general by the U. S. Army.³ The Nicoya complex forms the basement or oldest rocks in the region. They consist of complexly folded, faulted and partially metamorphosed sedimentary and igneous rocks, assigned to late Jurassic or Early Cretaceous time and are made of pillow basalts, basalt agglomerates, graywackes, cherts and limestones intruded by diabases and gabbros. There is a series of sedimentary rocks of Upper Cretaceous, Paleocene, Eocene, Oligocene, Miocene and Pliocene ages above the Nicoya Complex.

Intense volcanic activity has taken place during the late Miocene and Pliocene, extending into recent times in the eastern part of the country, and has spread volcanic material over the region.

The rocks of the mainland are primarily rhyolitic and andesitic tuff, containing interlayers of lava flow ranging from rhyolite to basalt. The origin of the soils of the Tempisque Valley are alluvial deposits derived largely from desintegration of volcanic ash of tuff. The rocks of the Nicoya Peninsula consist of complexly folded, faulted and altered sedimentary volcanic rocks with intruded dikes and sills of diabase and gabbro.

Soils

The soils of the region have not been studied in detail. Only general reconnaissance reports, and preliminary soil and classification

studies are available for areas showing potential for agricultural development.

A preliminary soil and land classification map was made in 1955 in connection with an irrigation project for the Tempisque Valley.⁴ A general reconnaissance report was also made on the soils of the region between latitude 9° 57' and 10° 06' N and longitude 84° 42' and 84° 58' W, in the Puntarenas Province (32). This report published in 1958 described the Chomes, El Palmar, Barranca, Los Negros and Aranjuez series, covering an area of 23,860 ha. These series are characterized in general by young sandy loam to clay loam alluvial soils which are slightly acid to neutral in pH (6.6 to 7.3). They have flat topography and poor internal drainage caused by high water tables, except for the Aranjuez series which is characterized by shallow, old, residual soils which have a stony phase on hills with slopes greater than 3%. The soils of this series are reddish clay loam to sandy loam, slightly acid to neutral in pH (6.2 to 6.8) and good internal drainage. All soils described in this report are low in soluble elements such as nitrogen, phosphorus and potassium.

Another brief report on the soils of the Nicoya Peninsula was prepared in 1965 by the Costa Rican Ministry of Agriculture. It describes the general characteristics of some soil profiles but no detail is given in the description or location of soil units. The lack of soil data has probably affected the development of agricultural programs in this region.

Vegetation and Agriculture

The vegetation of the Pacific "Tierra Caliente" of Costa Rica was

⁴Costa Rica. 1955. Tempisque Valley project investigation. U. S. D. I., Bur. of Reclamation; Costa Rican MAI and STICA. 16 p.

described by Standley (110) in 1937. He concluded that rainfall was the principal factor differentiating the vegetation of this region. He also mentioned that the vegetation could be described as xerophytic consisting of either forest or thickets of more or less deciduous trees and shrubs rather widely spaced. In large areas no shrubs or trees exist, or only scattered ones, and the land is a grassy savanna. The vegetation of this region is characterized by a high number of species of Leguminosae, as is usually the case in tropical regions with periods of limited rainfall. The principal large trees are represented by Enterolobium spp. (Guanacaste), Hura spp. (sand box trees), Anacardium excelsum, Sweetenia, various genera of Lauraceae, several Sapotaceae, Cassia grandis, Ceiba, Bombax, Terminalia and Cedrela. Smaller trees includes Dipterodendron, several species of Coccoloba, Tabebuia Chrysantha, Anona purpurea, Anacardium occidentalis Psidium guayaba, Simaruba glauca, Trema micrantha, and Bursera simaruba. Many of the shrubs found in this region, such as Hamelia patens and species of Casearia and Gonania, Cassia spp., Acacia farnesiana, Psidium guineense and various Anonaceae, are restricted to the Pacific coast of Costa Rica. One outstanding feature of the vegetation of the region is the presence of coyol palm, Acrocomia vinifera, and several genera of palm, such as Bactris, Desmoncus, Pyrenoglyphis and Scheelea, which are characteristic of the vegetation of the hot savannas of Latin America. Another outstanding feature of the vegetation is Cereus aragoni, the only tree cactus found in Costa Rica. Few epiphytes, principally Tillandsia; few orchids, such as Cattleya skinneri (guaria morada), Laelia and Epidendrum; and woody vines such as Vitis titrifolia, Cissus spp. and Combretum, also grow in this region in association with trees

and shrubs. The grasses are represented by several species of Andropogon, Aristida, Axonopus, Bouteloua, Eragostis, Hyparrhenia, Imperata, Panicum, Paspalum, Sporobolus, etc. They grow in these savannas forming a dense sward in association with a large number of Cyperaceae and Leguminosae, such as species of Centrosema, Crotalaria, Stylosanthes, Desmodium, Indigofera, etc. Standley (110) concluded that the savanna flora of Costa Rica was essentially South American, not only in genera but often in species having affinities with savannas in Panama, Venezuela and Colombia. Roseveare (99) reported in 1948 that the natural grasslands of the Pacific lowlands of Costa Rica were normally of two types, tall grasses such as Panicum maximum, Hyparrhenia rufa and Panicum purpurascens, and short grasses such as Paspalum notatum. He also indicated that jaraguagrass was a native grass to this region, which is not the case. He estimated the carrying capacity of the native range at 4.05 to 8.1 ha per mature animal. The cattle raised in the Guanacaste region represented over 40% of the total number of cattle in the country, although floods, droughts, pests and animal disease presented disadvantages which are absent in other regions in the country. The economy of the region is almost entirely agrarian and consists of cattle and annual crops which are affected by seasonal fluctuations of rainfall. It is the most important beef producing area in the country and provides approximately 36% of the cattle according to the latest agricultural census conducted in the country.⁵ The areas planted to cotton represent 92% of the total area planted in the country, rice 48%, corn 28%, beans 26% and sugar cane 19%. In

⁵Costa Rica. 1965. Censo agropecuario 1963. Direccion General de Estadistica y Censos. Ministerio de Economia y Hacienda, San Jose. 308 p.

addition, 49% of the exploited forest areas is present in the Guanacaste Province. However, the U. S. Army³ reported that the extensive cutting and burning which is used to cultivate the land either with annual crops or improved grasses, have resulted in the destruction of the forest resources and caused severe erosion of the land. It is significant to note⁵ that only 6% of the number of farms surveyed in this region were using fertilizer at that time. A total of 10,773 farms were surveyed which covered 772,074 ha of agricultural land.

EXPERIMENTAL PROCEDURES

Selection of Site

The field experiments were conducted at the Enrique Jiménez Nuñez Agricultural Experimental Station, Guanacaste Province, Costa Rica. The station is located at latitude 10° 21' N and longitude 85° 09' W, near Taboga in the Tempisque Valley, in the hot climate savanna in the Pacific lowlands of the country.

A three-year-old sward of jaraguagrass that had not been grazed or fertilized was selected to lay out the experiment. The topography is flat and the surface soil is primarily clay. Weed contamination was not sufficient to affect the purity of the grass stand.

Methods

Field experiments

A split-plot experiment consisting of three replications, three nitrogen treatments in the main plot and eight growth periods during the dry season, was established on October 13, 1965. The sward was cut by machete and the trash removed from the field prior to fertilization. The fertilization consisted of an equivalent of 0, 75, and 150 kg nitrogen per ha in the form of ammonium nitrate. In addition to it, an equivalent of 37.5 kg phosphorus per ha in the form of concentrated superphosphate was applied uniformly to the plots. The nitrogen treatments were identified as N₀, N₁, and N₂ corresponding to 0, 75, and 150 kg nitrogen per ha,

respectively. The subplots were harvested at 48, 62, 84, 92, 105, 115, 128, and 143 days of growth into the dry season after fertilization, corresponding to the following harvest dates: November 30, December 14, January 5, 13 and 26, February 9 and 18, and March 5, 1965-66, respectively. Strips of 3.5 m^2 were harvested with a sickle bar mower at a height of 5 cm. All the green forage from the harvested area was weighed and two samples were collected from each plot to determine dry matter production and for chemical analysis. The roots, in the top 20 cm of soil from an area of 0.25 m^2 , were sampled immediately after the forage was harvested on each harvest date. The roots were screened successively with 2 and 1 mm sieves and washed twice with tap water to remove impurities.

The harvested plots were allowed to regrow without further fertilization upon arrival of the rainy season at the beginning of May. The regrowth was harvested on August 19, 1966 to determine dry matter production and for chemical analysis to evaluate residual effects of the dry season and fertilizer applied at the beginning of the experiment. The harvest and sampling were conducted in a similar way for both the dry and rainy seasons.

All the plant material, forage and roots, was oven-dried, ground in a Wiley Mill to pass a 350-micron screen before being shipped to the University of Florida for chemical analysis.

Soil characterization

The soils of the experimental site were characterized the first part of December, just prior to the beginning of the dry season. Two pits were dug to a depth of 130 cm and field observations on horizon distribution, soil color, structure and consistency were made. At the

same time, clods were collected from the different horizons for bulk density measurements. Additional samples were obtained with a knife from the different horizons; they were air-dried, passed through a 2.0 mm sieve, placed in double paper bags and shipped to the University of Florida for physical and chemical analysis.

Physical Analysis

The soil samples collected in the field were analyzed in the laboratory for particle density, bulk density, total porosity, particle size distribution and the following moisture characteristics: moisture equivalent, wilting coefficient and permanent wilting point. Determination of particle density, bulk density and permanent wilting point were conducted at the Soil Analysis Laboratory, Ministry of Agriculture, San Jose, Costa Rica.

Particle density was determined using a pycnometer according to the standard method by Blake (8).

Bulk density was determined on clods following the method described by Blake (8).

Total porosity was calculated using the ratio of bulk density to particle density of the soil and subtracting from unity. Percentage pore space was obtained by multiplying by 100 according to the procedure given by Vomocil (124).

Particle size distribution was determined on a 50-g sample by the standard Bouyoucos method (12) with Calgon as a dispersing agent, but with twice the concentration recommended to assure dispersion.

Moisture equivalent approximates field capacity of fine textured soils and was determined by the standard method of centrifugation introduced by Briggs and McLane (18). Wilting coefficient approximates the permanent wilting point of fine textured soils and was calculated by dividing the values for moisture equivalent by the constant factor 1.84 according to calculations by Briggs and Shantz (19). Permanent wilting point was also determined by the use of the pressure membrane at a suction of 15.4 kg per cm² (15 atm) according to the method developed by Richards (98).

Chemical Analysis

Duplicate soil samples were taken to determine moisture content and the results of analysis were calculated on an oven-dry weight basis (105 C). The grass samples were dried at 70 C, and the results calculated on that oven-dry weight basis.

Duplicate ground root samples of 1 g each were ashed at 650 C for 1 hr in the muffle furnace to determine impurities remaining after washing with 0.1 N hydrochloric acid. The results of analysis were calculated on an oven-dry weight basis (70 C), free of impurities, primarily soil.

The soil pH was determined in a 2:1 water to soil suspension after 12 hr with a thin-glass electrode and a Corning pH meter Model 7. Enough solid potassium chloride was added to the suspension in water to make a 1 N salt solution. The pH was determined again after 30 min.

Organic carbon in the soil was determined by the Walkley-Black wet combustion method as modified by Walkley (126). The factor 1.724 was used to convert organic carbon to organic matter.

Total nitrogen in soil as well as in plant material was determined by a modified micro-Kjeldahl method described by Volk-Fontein⁶. Crude protein in the forage was calculated by multiplying nitrogen concentrations by the factor 6.25.

Total elementary phosphorus in soil was extracted by perchloric acid digestion and determined colorimetrically by the vanadomolybdophosphoric yellow color method described by Jackson (60). Soluble phosphorus was extracted from the soil with hydrofluoric-hydrochloric acid solution by the Bray and Kurtz method (14) and determined colorimetrically by the molybdenum blue method of Fiske and Subbarow (42).

Cation exchange capacity was determined by the method of ammonium saturation described by Chapman (29). The adsorbed ammonium was determined by the acid-sodium chloride method also described by Chapman (29).

Exchangeable cations were determined by extracting 10 g of soil with 1 N ammonium acetate according to the method of Peech et al. (91). The solution extracted was evaporated to dryness, the organic matter was oxidized with 6 N nitric acid solution and 30% hydrogen peroxide, and evaporated to dryness. The salts were taken up and diluted to 100 ml with 0.1 N hydrochloric acid solution.

Total cations in soil were determined on a 1-g sample by decomposition with hydrofluoric acid according to the method by Jackson (60). The solution was taken up and diluted to 100 ml with distilled deionized water.

⁶ Unpublished mimeographed sheet. Department of Soils, University of Florida, Gainesville, Fla.

Duplicate 1-g plant samples were dry ashed in a muffle furnace at 450 C for one hour for phosphorus and potassium, and at 550 C for 1 hr for calcium and magnesium. The salts were dissolved again in hydrochloric acid and diluted to a volume of 100 ml 0.1 N acid solution.

Determination of phosphorus in the plant material was made colorimetrically by the molybdenum blue method of Fiske and Subbarow (42).

Determination of potassium in the soil extracts and plant material was made with a Beckman DU Flame Spectrophotometer with hydrogen-oxygen burner assembly at 768 mu. Sodium was also determined with the same flame spectrophotometer but at 589 mu wave-length. Calcium was determined complexometrically by the versene titration method modified by Diehl (37); and magnesium was determined colorimetrically by the method of Carver and Robertson (28).

Forage Cellulose Digestion

Two-gram duplicate forage samples corresponding to the treatments of 150 kg nitrogen per ha at 48 days of growth and 0 nitrogen at 143 days of growth, respectively, were fermented for, 6, 12, 18, 24, 36, 48 and 72 hr with rumen liquid in an all-glass system according to the method described by Quicke et al. (94). The source of rumen liquid was a three-year-old fistulated steer fed with a constant diet consisting of bermuda-grass hay and soybean meal. Cellulose content in the samples was analyzed before and after fermentation by the method of Crampton and Maynard (33). The in vitro cellulose digested was expressed as the percent cellulose that was dissolved after fermentation, on the dry-weight basis (70 C). This experiment was conducted with samples from two different dates

to establish the fermentation pattern for the jaraguagrass. Then, duplicate forage samples corresponding to all the nitrogen treatments at 48, 92, and 143 days of growth, respectively, were compared for cellulose content and cellulose digestion using the same system and methods already described and for a fermentation period of 36 hr. This experiment was conducted on three different dates and the results expressed on the dry weight basis (70 C).

Statistical Analysis

The results from the field experiment and the forage cellulose digestibility were analyzed statistically by the method described by Snedecor (108).

RESULTS AND DISCUSSION

Soil Characterization

Profile description, and physical and chemical soil properties of the experimental site are given in Appendix Tables 13, 14 and 15, respectively. A soil sample from El Capulin, former Agricultural Experimental Station in Liberia, Guanacaste Province, Costa Rica, has been included in the last two tables for comparisons of the results of field experiments conducted by Andrade et al. (2) and those reported in this investigation. The morphological characteristics of this soil fall into the category of the Order Vertisol according to the Soil Survey Staff (109). Similar soils have been included by Dudal (39) under the general name of dark clay soils of tropical and subtropical regions. The physical properties of this soil seem to be adequate for field crops and pastures production, except possibly the total porosity and high clay content may present management problems, especially during the rainy season. The native fertility of this soil seems to be relatively low as indicated by its chemical properties. The total nitrogen, and the total and soluble phosphorus are relatively low, even though the organic matter content and pH seem to be adequate. The total cations and exchangeable bases were relatively high but there was an imbalance between some of the elements analyzed. The total and exchangeable calcium and magnesium seem to be in adequate amounts and proportions to support good plant growth, but the total and exchangeable potassium seem to be very low as compared to

the other bases, including sodium. Nitrogen and phosphorus are probably the two most deficient elements in the soil and probably affect pasture production at the present time.

Field Experiment During the Dry Season

Dry matter

The effect of nitrogen fertilization on the yields of oven-dry jaguagrass forage produced during the dry season is shown in Table 3. The forage dry matter production increased to more than 6,000 kg per ha to the middle of the dry season with application of nitrogen, and decreased after the seeding period when the plants in the field began to dry and deteriorate. This nitrogen effect was highly significant (1% level, Appendix Table 16). There were no significant differences between the N_1 and N_2 treatments and no interaction between the nitrogen treatments and the days of growth. At the same time, the dry matter production of the roots and crowns followed more or less the same pattern as the forage shoots, Table 4, but difficulties in sampling prevented statistical analysis of these results.

These results are similar to those presented by Andrade et al. (2) for the same region in Costa Rica; however, root data were not obtained in their study.

Troughton (117) summarized data for root weights produced by swards in different climatic regions, including the tropics, and under different conditions of sward age, management and depth of sampling. In general, the results reported in this investigation corresponded to the average figures reported by different investigators for tropical, as well as temperate species of grasses.

Table 3.- Yields of oven-dry jaraguagrass forage during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days)	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	kg/ha							
0	1381	667	1514	3285	2495	3143	2885	2276
75	4447	3219	4704	5857	5238	4771	4519	5333
150	3638	4047	5485	6704	5857	4971	5619	4981
AVE	3155	2644	3901	5282	4530	4295	4708	4197

¹ Days of growth after fertilization.

Table 4.- Yields of oven-dry jaraguagrass roots¹ during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ²	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	kg/ha							
0	2176	1484	3300	2571	2108	2304	2961	4659
75	2834	2108	3188	2655	4665	3110	2943	3227
150	3082	2603	2985	4062	3999	3163	3159	3583
Avg	2694	2065	3157	3096	3557	2859	3021	3823

¹Crowns included and corrected for impurities.

²Days of growth after fertilization.

Nitrogen

The effects of nitrogen fertilization and days of growth on forage nitrogen concentrations and total nitrogen contents during the dry season are shown in Fig. 2 and 3 and Appendix Tables 17 and 18. The nitrogen concentrations as well as the total nitrogen contents of the forage increased with nitrogen fertilization to more than 1.00% and 40 kg nitrogen per ha at 48 days of growth. However, there were interactions of nitrogen fertilization with days of growth on both nitrogen concentrations and contents (Appendix Tables 19 and 20) which nullified any nitrogen effect after 84 days of growth. These figures also show that the decrease in nitrogen concentrations was not entirely due to dilution from the increased dry matter production during the first part of the dry season, and that a substantial amount of nitrogen was actually lost from the forage shoots. The nitrogen concentrations and the total nitrogen contents of the roots and crowns increased with the nitrogen treatments (Appendix Tables 21 and 22) and tended to increase as the plant matured, as indicated by the days of growth into the dry season. These results were not analyzed statistically due to difficulties in sampling. However, there was a correlation between the total nitrogen content of the shoots and the total nitrogen content of the roots in the volume of soil sampled for each nitrogen fertilizer treatment. Fig. 4 shows that the total nitrogen contents of the forage shoots decreased as the total nitrogen contents of the roots increased during the dry season. The correlation coefficients for both nitrogen fertilizer treatments were significant at the 10% level and there was no correlation for the control treatment. The increase in total nitrogen contents of the roots could have been associated with the possibility of continuous nitrogen uptake from the

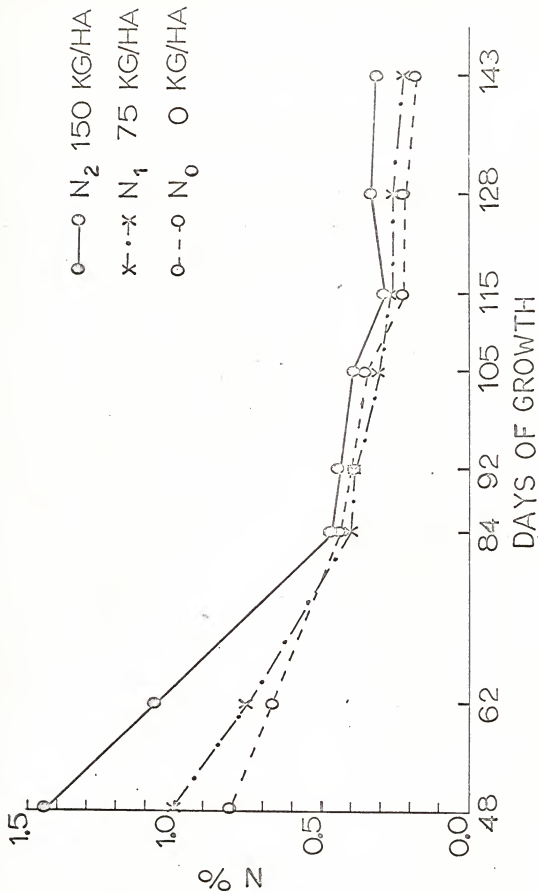


Fig. 2. Effects of nitrogen fertilization and days of growth on nitrogen concentrations in oven-dry jaraguagrass forage during the dry season.

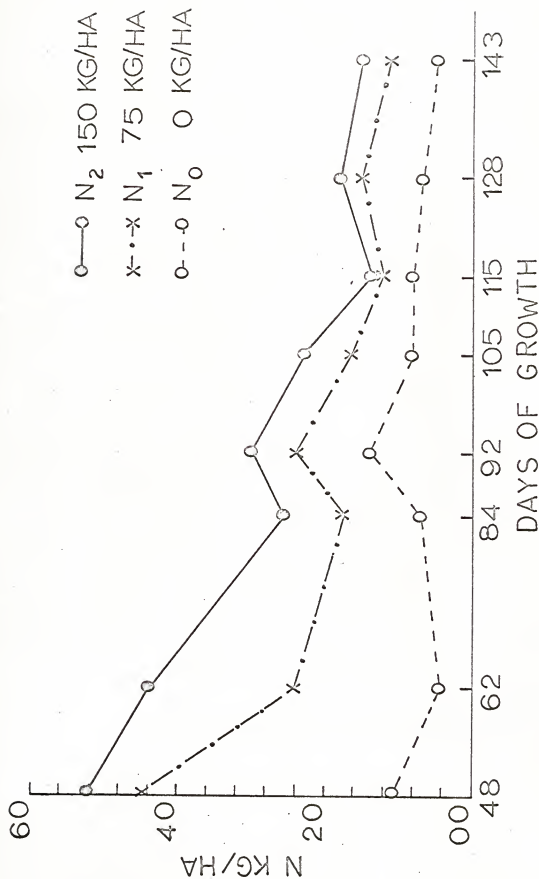


Fig. 3. Effects of nitrogen fertilization and days of growth on total nitrogen contents of oven-dry Jaraguagrass forage during the dry season.

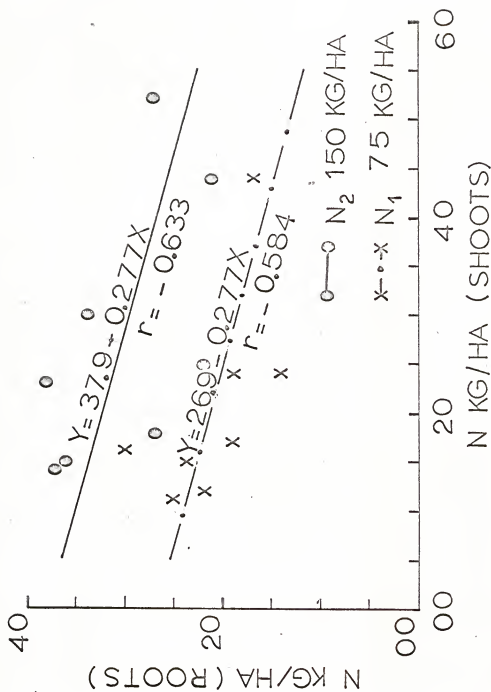


Fig. 4. Relationships between the total nitrogen contents of oven-dry jaraguagrass shoots and roots during the dry season.

fertilizer nitrogen even though the soil was dried, as was indicated by Volk (123), working with corn. However, it is significant that this possible nitrogen absorption did not result in an increase in the total nitrogen contents of the forage; on the contrary, the increase in total nitrogen contents of the roots occurred at the same time that the total nitrogen contents of the shoots decreased. These results do not eliminate completely the possibility of nitrogen uptake by the roots from the dry soil as a contributor to the increase in their total nitrogen content. Possibly this is one reason, together with the sampling error involved, for the low correlation coefficients found in this investigation. However, the total nitrogen contents of the roots during the dry season seemed to be closely associated with a factor or factors other than nitrogen uptake by the roots. Nitrogen translocation from the shoots could have contributed to the increase in the total nitrogen contents of the roots during the dry season.

The results of the present investigation seem to agree with those reported by Weinmann (129). However, he later explained (131) that the translocation of nitrogen and phosphorus to the roots resulted from the formation of water soluble decomposition products which occurred at maturity in dying leaves with the initiation of low autumn temperatures. Low temperature was not a factor in the present investigation and translocation seemed to take place even before the tissues began to dry under conditions of soil moisture stress in the field. The present investigation also shows results that agree with those of Andrade et al. (2), even though they worked with a different soil type from El Capulin Experimental Station in Liberia with a slightly different soil moisture regime.

The percentages of fertilizer nitrogen recovered in the forage at the different harvest dates are shown on Table 5. Nitrogen recovery was less than 45% for the N_1 treatment at 48 days of growth and decreased to less than 10% at the end of the experiment. If nitrogen recovery was the only measurement of fertilization efficiency, it was probably not economical to fertilize the grass at the end of the rainy season to increase forage quality for grazing during the dry season. However, the increase in dry matter production as the result of fertilization must also be considered.

These results are in accord with those found under similar conditions in the tropics and subtropics, according to the literature. It can be assumed that part of the nitrogen applied at the end of the rainy season was immobilized in the roots and would be translocated to the shoots with improvement in soil moisture.

Phosphorus

The effects of nitrogen fertilization and days of growth on forage phosphorus concentrations are shown in Fig. 5 and Appendix Table 23. The phosphorus concentrations were identical at the 48th day of growth, regardless of the nitrogen treatment. After that the concentrations decreased significantly (Appendix Table 24). Phosphorus concentrations decreased from 0.19% at the beginning to about 0.05% at the end of the experiment. The decrease was accelerated by increasing rates of nitrogen fertilization. Days of growth also had a highly significant effect on phosphorus concentrations. The interaction between nitrogen treatments and days of growth was also highly significant, meaning that these two factors affected the forage phosphorus concentrations differentially as the dry season progressed.

Table 5.- Fertilizer nitrogen recovered in oven-dry jaraguagrass forage during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ¹	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	----- % -----							
0	-	-	-	-	-	-	-	-
75	44.0	25.7	14.2	13.8	10.6	4.5	11.2	8.9
150	27.5	26.2	12.4	11.1	9.8	3.6	7.8	6.6
AVG	35.7	25.9	13.3	12.4	10.2	4.0	9.5	7.7

¹Days of growth after fertilization.

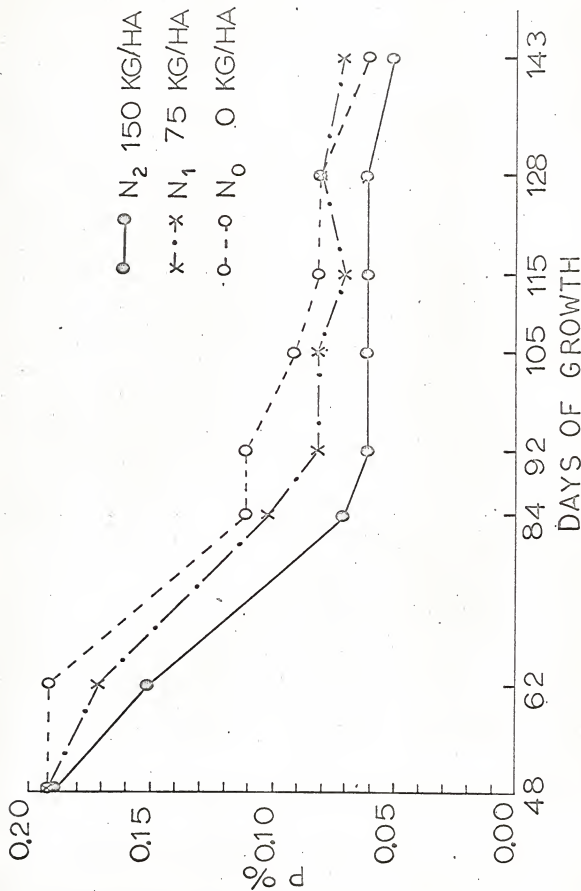


Fig. 5. Effects of nitrogen fertilization and days of growth on phosphorus concentrations in oven-dry jaraguagrass forage during the dry season.

The effects of nitrogen fertilization and days of growth on total forage phosphorus contents are shown in Fig. 6 and Appendix Table 25. Total forage phosphorus increased with nitrogen fertilization mainly as the result of the increase in forage yield. Total phosphorus was 8.6 kg per ha at the beginning of the experiment with the N_1 treatment and decreased as the dry season progressed. The effects of nitrogen treatments and days of growth were highly significant (Appendix Table 26). There was also a highly significant interaction of these two factors. This indicated that losses of forage phosphorus were not due to dilution from the increase in dry matter as the plant grew and occurred regardless of the nitrogen fertilization.

Fig. 7 shows the relationship between forage nitrogen and phosphorus concentrations for each nitrogen treatment. There was a highly significant correlation between the concentrations of these two elements in the forage for each nitrogen treatment. There was also a highly significant correlation between the total nitrogen and total phosphorus contents of the forage for each nitrogen treatment, as shown in Fig. 8. These relationships indicated that the phosphorus was moving out of the shoots at a rate proportional to the nitrogen content of the forage at the beginning of the dry season.

Phosphorus is a very stable element in the metabolism of plants and it is improbable that it could have been volatilized from the shoots, at least in such quantities as shown in the present investigation. There was not sufficient rainfall to have leached phosphorus from the leaves and no appreciable loss of leaves occurred from the plants during the course of this investigation. These data suggest that phosphorus as well as

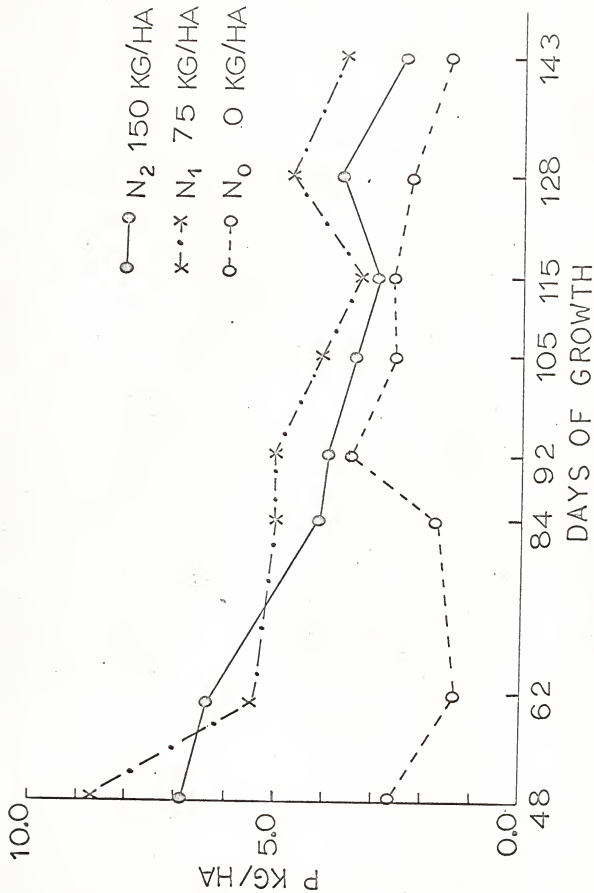


Fig. 6. Effects of nitrogen fertilization and days of growth on total phosphorus contents of oven-dry Jaraguagrass forage during the dry season.

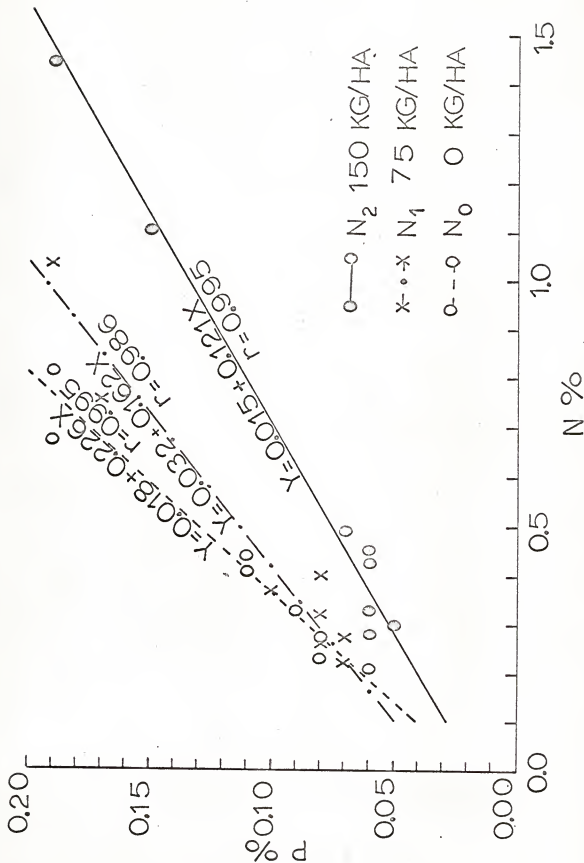


Fig. 7. Relationships between the nitrogen and phosphorus concentrations in oven-dry Jaraguagrass forage during the dry season.

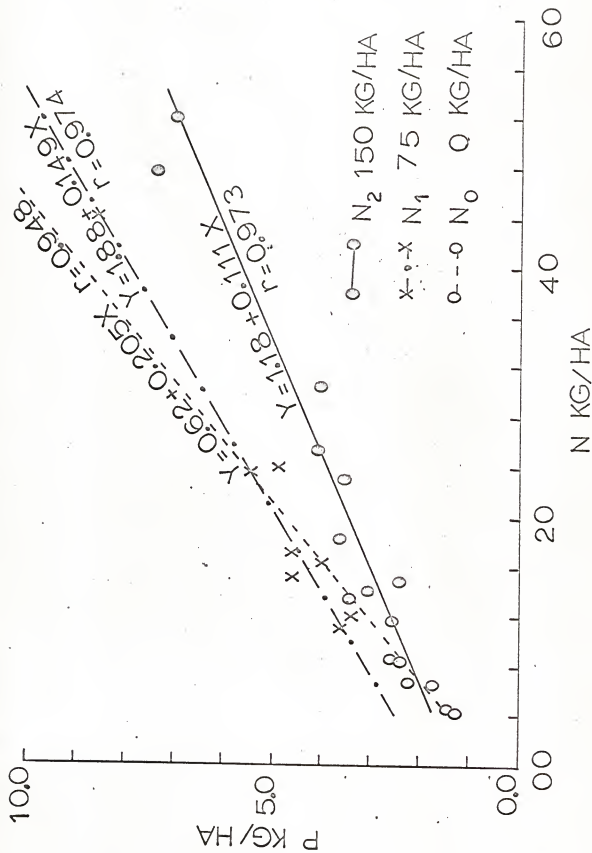


Fig. 8. Relationships between the total nitrogen and total phosphorus contents of oven-dry jaraguagrass forage during the dry season.

nitrogen was translocated from the shoots to the roots as the result of soil moisture stress.

Appendix Tables 27 and 28 show the phosphorus concentrations and total phosphorus contents of the roots during the dry season. There was no relationship between the phosphorus contents of the shoots and the roots of the grass in the present investigation.

Field Experiment During the Rainy Season

Dry matter

The residual effect of nitrogen fertilization on the yields of oven-dry jaraguagrass forage regrowth during the rainy season is shown in Table 6. There was no significant effect of the nitrogen treatments on the yields of forage (Appendix Table 29). This indicates no residual effect of the nitrogen applied at the beginning of experiment on plant regrowth after initial harvest. The effect of days of growth on dry matter production during the rainy season was significant at the 5% level. However, there was a highly significant interaction between the nitrogen treatments and days of growth. The effect of the nitrogen accumulated in the roots on plant regrowth is shown by the fact that the average dry matter yield for all treatments increased as the days after initial harvest decreased, as shown in Table 6. The plants harvested on November 30 accumulated less nitrogen in the roots than those harvested on March 5, as shown in Appendix Table 22. The plant regrowth started essentially at the same time with the beginning of the rainy season during the first week of May, so the difference in yields could not be attributed to difference in the days of growth at the time of sampling. The interaction between the nitrogen treatments and the days of growth

Table 6.- Yields of oven-dry jaraguagrass forage regrowth during the rainy season

N Applied	Harvest dates of first growth							
	Nov. 30 (262 days) ¹	Dec. 14 (248 days)	Jan. 5 (226 days)	Jan. 13 (218 days)	Jan. 26 (205 days)	Feb. 9 (195 days)	Feb. 18 (182 days)	Mar. 5 (167 days)
kg/ha	----- kg/ha -----							
0	7830	8365	6318	7830	7229	7531	7301	8183
75	5790	6221	8333	7623	7803	9929	8885	9007
150	6053	6693	7630	7364	8547	6220	9077	7277
AVG	6558	7093	7427	7605	7860	7893	8421	8155

¹ Days after initial harvest.

can be explained by the fact that more nitrogen had accumulated in the roots as a result of fertilization at the end of the previous rainy season and from translocation from the shoots to the roots as the dry season progressed. Therefore, the nitrogen that accumulated in the roots during the dry season had a beneficial effect on plant regrowth as soon as the soil moisture condition improved with the beginning of the rainy season. The lack of significance for nitrogen treatments suggested that the unrecovered nitrogen was held in an unavailable organic form in the soil since there was no significant rainfall to cause leaching.

Nitrogen

The effects of nitrogen fertilization on nitrogen concentration and total nitrogen content of the forage during the rainy season are shown in Tables 7 and 8. There was no significant effect of the nitrogen treatments on the nitrogen concentrations or on the total nitrogen contents of the forage during the following rainy season (Appendix Tables 30 and 31). This indicated no residual effect of the nitrogen applied at the beginning of the experiment on nitrogen concentrations or total nitrogen contents of the forage during the rainy season.

Appendix Tables 30 and 31 also show that the effect of days of growth on nitrogen concentrations and total nitrogen contents of the forage during the rainy season were significant in both cases. However, the interactions between the nitrogen treatments and the days of growth on nitrogen concentrations and total nitrogen contents of the forage were significant at the 5% and 1% levels, respectively. This seemed to indicate that the nitrogen accumulated in the roots during the dry season was translocated to the shoots when the soil moisture condition improved. The interaction of nitrogen treatment with days of growth could be

Table 7.- Nitrogen concentrations in oven-dry Jaraguagrass forage regrowth during the rainy season

N Applied	Harvest dates of first growth							
	Nov. 30 (262 days) ¹	Dec. 14 (248 days)	Jan. 5 (226 days)	Jan. 13 (218 days)	Jan. 26 (205 days)	Feb. 9 (195 days)	Feb. 18 (182 days)	Mar. 5 (167 days)
kg/ha	----- % -----							
0	0.42	0.32	0.36	0.34	0.45	0.42	0.33	0.32
75	0.40	0.37	0.38	0.40	0.37	0.35	0.37	0.32
150	0.40	0.40	0.35	0.41	0.36	0.40	0.40	0.37
AVG	0.41	0.36	0.36	0.38	0.39	0.39	0.36	0.33

¹ Days after initial harvest.

Table 8.- Total nitrogen contents of oven-dry jaraguagrass forage regrowth during the rainy season

N Applied kg/ha	Harvest dates of first growth ¹							
	Nov. 30	Dec. 14	Jan. 5	Jan. 13	Jan. 26	Feb. 9	Feb. 18	Mar. 5
	-----	-----	-----	-----	-----	-----	-----	-----
0	33.3	27.0	23.0	26.3	33.0	32.0	24.3	26.0
75	22.6	23.0	30.3	30.3	29.3	34.3	32.0	29.0
150	23.6	26.3	26.3	29.0	31.0	25.3	36.6	26.3
Avg	26.5	25.4	26.5	28.5	31.1	30.5	30.9	27.1

¹ Days from initial harvest to August 19 were 262, 248, 226, 218, 205, 195, 182, and 167 days, respectively.

explained by the fact that more nitrogen accumulated in the roots with nitrogen fertilization.

Forage Quality

Crude protein

The crude protein concentrations and total crude protein contents of the forage increased with fertilization up to 9.00% and 327 kg per ha, respectively, with the N_2 treatment at 48 days of growth and then declined very rapidly as the dry season progressed, Tables 9 and 10. The effect of nitrogen fertilization on the crude protein concentrations in the forage did not last beyond the third harvest date and after that it was essentially the same, regardless of the nitrogen treatment. The decline in the total crude protein of the forage during the dry season was 2.48, 2.15 and 0.42 kg per ha per day corresponding to the N_2 , N_1 and N_0 treatments, respectively. The total crude protein contents of the forage at the end of the dry season corresponding to the nitrogen fertilization was high compared to the check treatment because of the higher amount of dry matter produced.

The levels of crude protein in the forage were below those recommended for normal growth of beef cattle by the National Research Council (50), except possibly for the N_2 treatment at the first harvest date. This indicated that the jaraguagrass forage would not be able to supply during the dry season the protein required for normal growth by beef cattle, even with high rates of nitrogen fertilization at the end of the rainy season. It is expected that cattle, grazing this type of forage as their sole source of protein, will lose weight since the crude protein

Table 9.- Crude protein concentrations¹ in oven-dry Jaraguagrass forage during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ²	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	-----	-----	-----	-----	-----	-----	-----	-----
0	5.06	4.20	2.77	2.56	2.10	1.71	1.45	1.33
75	6.27	4.68	2.31	2.56	1.95	1.52	1.64	1.37
150	9.00	6.71	2.91	2.79	2.45	1.77	2.08	1.85
Avg	6.78	5.20	2.66	2.64	2.17	1.67	1.72	1.52

¹ Nitrogen concentrations x 6.25.

² Days of growth after fertilization.

Table 10.- Total crude protein contents¹ of oven-dry jaraguagrass forage during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ²	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	kg/ha							
0	68.6	27.3	41.3	85.3	52.0	54.0	41.6	29.0
75	275.0	147.6	108.0	150.0	102.0	75.0	93.6	70.6
150	327.0	272.6	158.3	189.6	143.6	87.3	114.3	91.6
AVG	223.5	149.1	102.5	141.6	99.2	72.1	83.1	63.7

¹Total nitrogen contents x 6.25.

²Days of growth after fertilization.

concentrations declined to less than 3% by the third harvest date. Miller et al. (80) indicated that levels of this magnitude will not provide maintenance requirements for beef cattle.

The residual effect of nitrogen fertilization on forage protein concentrations during the rainy season is shown in Table 11. Levels of crude protein in all the treatments were below those indicated as the minimum requirement for beef cattle maintenance. A protein supplement should be used during the entire year to provide adequate levels of protein for animals grazing jaraguagrass, under conditions similar to those encountered in the present investigation.

Cellulose concentrations and in vitro cellulose digestion

Fig. 9 shows the in vitro cellulose digestion pattern for two qualities of jaraguagrass forage for different fermentation periods. The higher quality forage produced higher cellulose digestibility.

Table 12 shows the cellulose concentrations and in vitro cellulose digestion of the forage during the dry season. The nitrogen fertilization increased the cellulose concentrations in the forage and the digestion; both effects were highly significant (Appendix Tables 32 and 33). The cellulose concentrations in the forage increased as the dry season progressed, but its digestion decreased at the same time. Both effects were highly significant. There were also highly significant interactions between these two factors on cellulose concentrations in the forage and the digestion.

These data suggested that the quality of the jaraguagrass forage in terms of its cellulose concentrations, and cellulose digestion was fairly good, even at the end of the experiment during the dry season.

Table 11.- Crude protein concentrations¹ in oven-dry jaraguagrass forage regrowth during the rainy season

N Applied	Harvest dates of first growth ²								
	Nov. 30	Dec 14	Jan 5	Jan 13	Jan 26	Feb 9	Feb 18	Mar 5	
kg/ha	----- % -----								
0	2.62	2.02	2.27	2.10	2.83	2.64	2.08	2.02	
75	2.47	2.29	2.35	2.51	2.33	2.16	2.29	2.02	
150	2.49	2.52	2.18	2.54	2.27	2.52	2.52	2.29	
AVG	2.52	2.27	2.26	2.38	2.47	2.44	2.29	2.11	

¹ Nitrogen concentrations x 6.25.

² Days from initial harvest to August 19 were 262, 248, 226, 218, 205, 195, 182, and 167 days, respectively.

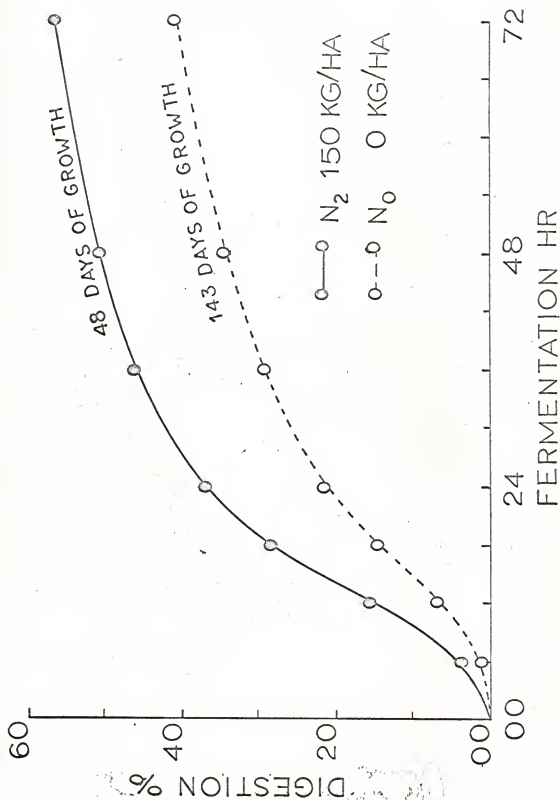


Fig. 9. In vitro cellulose digestion of oven-dry jaraguagrass forage at different fermentation periods.

Table 12.- Cellulose concentrations and in vitro cellulose digestion of oven-dry Jaraguagrass forage during the dry season

N Applied	Harvest of first growth					
	Nov. 30 48 days ¹		Jan. 13 92 days		Mar. 5 143 days	
	Cellulose	Digestion	Cellulose	Digestion	Cellulose	Digestion
kg/ha	----- % -----					
0	29.7	44.2	32.5	39.3	31.9	32.0
75	30.9	45.8	35.2	39.3	37.3	31.3
150	29.3	49.1	35.8	41.7	37.9	38.8
Avg	30.0	46.3	34.5	40.1	35.7	34.0

¹ Days of growth after fertilization.

However, the forage intake by the animals could be low due to the low crude protein concentrations at this stage of growth affecting the gross energy intake by the animals. Jaraguagrass could be used as a roughage in dry tropical conditions combined with a protein supplement and molasses to improve palatability and forage intake.

Mineral composition

Appendix Tables 23, 34, 35, and 36 show the phosphorus, potassium, calcium and magnesium concentrations in the forage during the dry decreased as the dry season progressed. At the same time, the calcium concentration remained more or less constant. The concentration of these elements in the forage were more or less the same in all the plots sampled during the rainy season, as shown in Appendix Tables 37, 38, 39 and 40. The levels of phosphorus in the forage during the dry and rainy seasons were below the minimum recommended by Cunha et al. (34) for beef cattle in Florida. The levels of the other minerals were always above the minima recommended for Florida. However, it is important to notice that the calcium-phosphorus ratio was almost always above 4:1 which could also adversely affect animal performance, particularly with low phosphorus concentrations. The phosphorus deficiency in the forage seemed to be associated with deficiency of this element in the soil (Appendix Table 15), and movement of the nutrient in the plant as the dry season progressed. This suggests the necessity to supply additional phosphorus to the animals throughout the year to improve rates of growth and reproduction under similar conditions in the tropics.

The evaluation of the jaraguagrass forage quality in this experiment indicated that this forage plant was unsuitable for an intensive

grazing program during the dry season, even with fertilization. The agronomic qualities of the plant could be useful to provide roughage if feed supplement were used during the dry season. There is also the possibility of including a legume in the pasture or nitrogen fertilization during the rainy season to improve the pasture quality. However, some other tropical grasses could be adapted to the region and give better results than jaraguagrass, if they were properly managed.

SUMMARY AND CONCLUSIONS

The effect of nitrogen fertilization during the latter part of the rainy season on the movement of nutrients from a tropical grass, jaraguagrass (Hyparrhenia rufa (Nees) Stapf), during the dry season was studied in a hot savanna in Guanacaste Province, Costa Rica. The nutritive value of the forage harvested during the dry and following rainy season was also evaluated. The experimental design was a split-plot with three replications, three nitrogen treatments (0, 75 and 150 kg nitrogen per ha in the form of ammonium nitrate), and eight harvests along the dry season on a three-year-old sward that had not been grazed or fertilized before. The experiment was established on October 13, 1965 after the forage accumulated during the earlier part of the rainy season was cut by machete and the trash removed. An equivalent of 37.5 kg phosphorus per ha in the form of concentrated superphosphate was applied uniformly to all the plots. The subplots were harvested at 48, 62, 84, 92, 105, 115, 128 and 143 days of growth into the dry season for determination of dry matter production, and nitrogen, phosphorus, potassium, calcium and magnesium concentrations in the forage. The roots in the top 20 cm of soil were sampled at each harvest to determine dry matter, and nitrogen and phosphorus concentrations. Cellulose concentrations and in vitro cellulose digestion after 36 hr of fermentation were determined on forage samples from the 48-, 92- and 143-day growth periods to determine the value of the forage as a roughage, after the in vitro cellulose digestion

pattern for the grass was established at 6, 12, 18, 24, 36, 48 and 74 hr, respectively. In addition, the soil profile was characterized and samples were taken for physical and chemical analysis.

The characteristics of the soil fall into the category of the Order Vertisol. The physical properties of the soil seemed to be adequate for field crops and pasture productions. The native fertility seemed to be low, especially in nitrogen and phosphorus.

Dry matter production increased with nitrogen fertilization to the middle of the dry season and decreased after the seed production when the plants in the field began to dry and deteriorate. The effect of nitrogen was highly significant but there was no significant difference between the N_1 and N_2 treatments and no interaction between nitrogen treatments and days of growth. At the same time the dry matter of the roots followed more or less the same pattern as the shoots, although difficulties in sampling prevented making any definitive conclusions concerning these results.

Forage nitrogen concentrations as well as the total nitrogen contents increased with nitrogen fertilization to 1.44% and 52.3 kg per ha, respectively, with the N_2 treatment at 48 days of growth. However, there was a highly significant interaction with days of growth which nullified any nitrogen effect after 84 days. The forage nitrogen concentration decreased to 0.3% and the nitrogen content to 14.6 kg per ha with the N_2 treatment at the end of the experiment. The nitrogen concentrations and the total nitrogen contents of the roots also increased with the N_2 treatment and tended to increase as the plant matured. There were significant

correlations between the total nitrogen contents of the shoots and the roots for the nitrogen fertilizer treatments but no correlation was found for the control treatment.

Nitrogen recovery by the herbage from the applied fertilizer was less than 45% for the first harvest date and decreased to less than 10% at the end of the experiment, regardless of the nitrogen treatment.

The concentrations of phosphorus in the shoots decreased from about 0.19% at the beginning of the experiment to about 0.05% at the end and the decrease was accelerated by increasing rates of nitrogen fertilization. At the same time the concentrations of phosphorus in the roots tended to increase as the plants matured. There was a direct relationship between the nitrogen and phosphorus concentrations in the shoots at different stages of maturity and the correlation was highly significant for each nitrogen treatment. The total phosphorus contents of the forage decreased from 6.9 kg per ha at the beginning of the experiment to 2.4 at the end, with the N_2 treatment. There was a direct relationship between the total nitrogen and total phosphorus contents of the forage at different stages of maturity and the correlation was highly significant for each nitrogen treatment.

The cellulose concentrations in the forage increased significantly with nitrogen fertilization from about 30% to about 38% at the end of the experiment. There was also a highly significant interaction with the days of growth. The in vitro cellulose digestion increased with nitrogen fertilization from 44% to about 49% at the first harvest date. There was a highly significant decrease in the digestion of the forage as the plants matured and the interaction of nitrogen treatments with days of growth was highly significant.

The same plots were harvested on August 19, 1966 in the middle of the rainy season after completion of the first part of the experiment. The plots were not refertilized and the purpose of this second part was to evaluate residual effects of the fertilizer applied at the beginning of the experiment, and dry-season harvest dates on plant regrowth. There was no significant residual effect of the applied nitrogen on the dry matter production, nitrogen concentration and total nitrogen content of the forage. Harvest dates had a significant effect on the regrowth. The interaction of the nitrogen treatment with days of growth was significant for dry matter production, nitrogen concentrations and total forage nitrogen content.

The nutritive value of the forage in terms of crude protein was low for both the dry and rainy seasons. The cellulose contents and digestion values seemed to be fairly good for the dry season and this could be compensated by the amount of dry matter produced which could support a high stocking rate if a protein supplement were used. The phosphorus concentrations in the forage were low for both seasons but the potassium, calcium and magnesium concentrations seemed to be adequate for cattle production throughout the year. The forage phosphorus deficiency may have been associated with the deficiency of this element in the soil.

The following conclusions can be drawn from the field experiment to support the hypothesis of translocation from the shoots to the roots of Jaraguagrass as being the main mechanism responsible for losses of nitrogen and phosphorus from the herbage during the dry season.

1. Nitrogen moved out of the herbage regardless of nitrogen fertilization to an equivalent of 150 kg of the element per ha applied at the end of the rainy season.
2. Volatilization was not likely responsible for all the nitrogen lost because of the large quantities involved and no known mechanisms of nitrogen volatilization from the leaf occurs in green plants, except in very small quantities in some species, according to the literature.
3. A comparison of these results with data obtained by Andrade et al. (2) in the same savanna region in Costa Rica showed that the movement of nitrogen from the grass herbage occurred in soils of different textures and under slightly different moisture regimes.
4. There was a tendency for the dry weights and total nitrogen contents of the roots to increase during the dry season after fertilization with nitrogen at the end of the rainy season. There seemed to be a direct relationship between the decrease of the total nitrogen content of the shoots and the increase of the total nitrogen content of the roots with nitrogen fertilization as the dry season progressed.
5. There was a rapid decrease in the phosphorus content of the herbage during the dry season. There was little possibility that phosphorus could have been volatilized by any known mechanisms in the green plants, so it must have been translocated to the roots during the soil moisture stress. Nitrogen and phosphorus may have been involved in the same process or

processes because of the close relationship of these two elements in plant metabolism.

6. The nitrogen and phosphorus movements from the herbage were closely related and occurred in the plant while it was still growing, as indicated by the increase in dry matter production. Protein metabolism in the plant changed during the dry season regardless of the nitrogen fertilization at the end of the rainy season.
7. The decrease in soil moisture during the dry season seemed to be the main environmental factor determining the change in plant nitrogen metabolism based on field data, observations and information reported in the literature. Changes in night temperatures and photoperiodism may also have had some effect

APPENDIX

Table 13.- Profile descriptions of the soil from the experimental area

Depth	Description
cm	<u>Pit 1</u>
0-20	Dark reddish brown (5 YR 3/2) clay; medium granular structure; slightly firm, friable; intermediate drainage; gradual boundary; pH in H ₂ O, 6.3; pH in <u>N</u> KCl, 5.5.
20-40	Dark yellowish brown (10 YR 4/4) clay; medium-coarse granular structure; firm friable; intermediate drainage; clear boundary; small yellow concretions; pH in H ₂ O, 6.3; pH in <u>N</u> KCl, 5.5.
40-95	Very dark gray (5 YR 3/1) clay; coarse blocky structure; firm, plastic, sticky; poor drainage; clear boundary; small white and yellow concretions; pH in H ₂ O, 6.1; pH in <u>N</u> KCl, 5.4.
95-130	Dark yellowish brown (10 YR 4/4) clay; coarse prismatic structure; firm, plastic, sticky; poor drainage; clear boundary; large white and yellow concretions, few small stones; pH in H ₂ O, 6.5; pH in <u>N</u> KCl, 5.4.
	<u>Pit 2</u>
0-20	Dark reddish brown (5 YR 3/2) clay; medium granular structure; slightly firm, friable; intermediate drainage; gradual boundary; pH in H ₂ O, 6.4; pH in <u>N</u> KCl, 5.5.
20-40	Dark yellowish brown (10 YR 4/4) clay; crumbs structure; slightly firm, friable, intermediate drainage; clear boundary; small yellow concretions; pH in H ₂ O, 6.6; pH in <u>N</u> KCl, 5.4.
40-100	Very dark gray (5 YR 3/1) clay; coarse to very coarse blocky structure; firm, plastic, sticky; poor drainage, mottled; small white and yellow concretions, few small stones; pH in H ₂ O, 6.7; pH in <u>N</u> KCl, 5.3.
100-130	Dark yellowish brown (10 YR 4/4) clay; medium blocky structure; firm, plastic, sticky; poor drainage; large white and yellow concretions, few small stones; pH in H ₂ O, 6.7; pH in <u>N</u> KCl, 5.4.

Table 14.- Physical properties of soils

Particle size distribution							Moisture characteristics		
Depth	Particle density	Bulk density	Total porosity	Sand	Silt	Clay	Moisture equivalent	Permanent wilting point	Wilting coefficient
cm	g/cm ³	g/cm ³	%	-----	%	-----	-----	%	-----
Pit 1									
0-20	2.38	1.32	44.5	29.9	27.4	42.7	39.7	14.0	21.6
20-40	2.45	1.33	45.7	25.3	27.3	47.4	39.8	20.6	21.6
40-60	2.55	1.38	45.9	11.4	21.3	67.3	45.1	20.7	24.5
60-80	2.58	1.38	46.5	4.4	12.9	82.7	52.8	25.1	28.7
Pit 2									
0-20	2.59	1.31	49.4	30.4	24.9	44.7	38.3	19.6	20.8
20-40	2.61	1.31	49.8	14.0	27.5	58.5	42.4	20.8	23.0
40-60	2.70	----	----	10.3	18.8	70.9	47.5	22.4	25.8
60-80	----	1.38	----	2.0	12.6	85.4	56.4	30.9	30.6
El Capulin									
0-20	----	----	----	29.2	33.6	37.2	31.4	----	17.1

Table 15.- Chemical properties of soils

Depth	H ₂ O	pH	N KCl	OM	Total N	C/N Ratio	Total P	Soluble P	CEC	Cations						
										Exchangeable						
										Ca	Mg	K	Na	Ca	Mg	Total
cm				%	%		ppm	ppm	meq/100	-----	meq/100	-----	-----	-----	-----	%
<u>Pit 1</u>																
0-20	6.3	5.5	5.5	5.17	0.16	18.7	420	4	24.0	20.2	3.4	0.2	1.0	3.7	0.7	1.2
20-40	6.3	5.5	5.5	3.05	0.11	16.1	325	3	30.7	21.8	4.9	0.2	1.6	3.7	1.0	0.9
40-60	6.1	5.4	5.4	1.95	0.06	18.8	285	1	38.8	24.2	7.0	0.2	1.6	8.1	0.5	0.6
60-80	6.5	5.4	5.4	1.34	0.06	13.0	255	1	41.4	27.3	10.2	0.2	1.6	8.8	0.3	0.4
<u>Pit 2</u>																
0-20	6.4	5.5	5.5	5.36	0.18	17.2	445	3	26.7	17.5	3.7	0.2	1.2	5.1	0.3	0.6
20-40	6.6	5.4	5.4	2.20	0.11	11.6	330	3	30.7	18.2	4.9	0.2	1.4	5.9	0.3	0.4
40-60	6.7	5.3	5.3	1.38	0.07	11.4	260	1	33.4	22.4	7.2	0.2	1.4	6.8	0.3	1.1
60-80	6.7	5.4	5.4	0.93	0.06	9.0	260	1	48.8	27.7	10.4	0.2	1.9	7.8	0.3	0.7
<u>El Capulin</u>																
0-20	6.4	5.5	5.5	4.51	0.18	14.5	345	12.6	14.7	9.1	1.1	0.9	0.9	3.0	0.1	1.4

Table 16.- Analysis of variance for yields of oven-dry jaraguagrass forage during the dry season

Source of variation	Degrees of freedom	Mean squares	F
Main plots:			
N treatments	2	64,259,937	68.95**
Blocks	2	238,525	
Main plot error	4	932,011	
Sub-plots:			
Days of growth	7	6,349,648	9.99**
Days X N treatments	14	629,347	
Sub-plot error	42	635,367	

**Significant at the 1% level.

Table 17.- Nitrogen concentrations in oven-dry Jaraguagrass forage during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ¹	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	----- % -----							
0	0.81	0.67	0.44	0.41	0.34	0.27	0.23	0.21
75	1.00	0.75	0.40	0.41	0.31	0.24	0.26	0.22
150	1.44	1.08	0.47	0.45	0.39	0.28	0.33	0.30
AVG	1.08	0.83	0.44	0.42	0.35	0.26	0.27	0.24

¹ Days of growth after fertilization.

Table 18.- Total nitrogen contents of oven-dry jaraguagrass forage during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ¹	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	kg/ha							
0	11.0	4.3	6.6	13.6	8.3	8.6	6.6	4.6
75	44.0	23.6	17.3	24.0	16.3	12.0	15.0	11.3
150	52.3	43.6	25.3	30.3	23.0	14.0	18.3	14.6
AVE	35.7	23.8	16.4	22.6	15.8	11.5	13.3	10.1

¹ Days of growth after fertilization.

Table 19.- Analysis of variance for nitrogen concentrations in oven-dry jaraguagrass forage during the dry season

Source of variation	Degrees of freedom	Mean squares	F
Main plots:			
N treatments	2	0.2004	111.33**
Blocks	2	0.0032	
Main plot error	4	0.0018	
Sub-plots:			
Days of growth	7	0.8447	703.91**
Days X N treatments	14	0.0402	33.50**
Sub-plot error	42	0.0012	

**Significant at the 1% level.

Table 20.- Analysis of variance for total nitrogen contents of oven-dry jaraguagrass forage during the dry season

Source of variation	Degrees of freedom	Mean squares	F
Main plots:			
N treatments	2	2.385	33.12**
Blocks	2	38	
Main plot error	4	72	
Sub-plots:			
Days of growth	7	641	18.31**
Days X N treatments	14	150	4.28**
Sub-plot error	42	35	

**Significant at the 1% level.

Table 21.- Nitrogen concentrations in oven-dry Jaraguagrass roots¹ during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ²	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	----- % -----							
0	0.93	0.62	0.78	0.83	0.94	0.98	1.08	0.82
75	0.79	0.84	0.71	0.92	0.89	0.98	1.02	1.06
150	1.01	1.12	0.95	1.04	1.28	1.48	1.24	1.27
Avg	0.91	0.86	0.86	0.93	1.03	1.14	1.11	1.05

¹Corrected for impurities.

²Days of growth after fertilization.

Table 22.- Total nitrogen contents of oven-dry jaraguagrass roots¹
during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ²	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	kg/ha							
0	16	8	19	22	17	18	28	29
75	17	14	19	19	30	22	24	25
150	27	21	22	34	38	37	27	36
Avg	20	14	20	25	28	26	26	30

¹Crowns included and corrected for impurities.

²Days of growth after fertilization.

Table 23.- Phosphorus concentrations in oven-dry Jaraguagrass
forage during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ¹	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	----- % -----							
0	0.19	0.19	0.11	0.11	0.09	0.08	0.08	0.06
75	0.19	0.17	0.10	0.08	0.08	0.07	0.08	0.07
150	0.19	0.15	0.07	0.06	0.06	0.06	0.06	0.05
Avg	0.19	0.17	0.09	0.08	0.08	0.07	0.07	0.06

¹ Days of growth after fertilization.

Table 24.- Analysis of variance for phosphorus concentrations in oven-dry jaraguagrass forage during the dry season

Source of variation	Degrees of freedom	Mean squares	F
Main plots:			
N treatments	2	0.00435	17.4*
Blocks	2	0.00020	
Main plot error	4	0.00025	
Sub-plots:			
Days of growth	7	0.02078	109.3**
Days X N treatments	14	0.00093	4.9**
Sub-plot error	42	0.00019	

* Significant at the 5% level.

** Significant at the 1% level.

Table 25.- Total phosphorus contents of oven-dry Jaraguagrass forage during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ¹	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	kg/ha							
0	2.6	1.3	1.8	3.4	2.5	2.6	2.3	1.5
75	8.6	5.4	4.7	4.9	4.0	3.4	4.7	3.7
150	6.9	6.4	4.1	4.0	3.5	3.0	3.7	2.4
AVG	6.0	4.3	3.5	4.1	3.3	3.0	3.5	2.5

¹ Days of growth after fertilization.

Table 26.- Analysis of variance for total phosphorus contents of oven-dry jaraguagrass forage during the dry season

Source of variation	Degrees of freedom	Mean squares	F
Main plots:			
N treatments	2	46.21	19.55**
Blocks	2	1.73	
Main plot error	4	2.35	
Sub-plots:			
Days of growth	7	10.43	10.08**
Days X N treatment	14	3.35	3.24**
Sub-plot error	42	1.03	

** Significant at the 1% level.

Table 27.- Phosphorus concentrations in oven-dry jaraguagrass roots¹
during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ¹	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	----- % -----							
0	0.08	0.08	0.08	0.07	0.10	0.09	0.09	0.09
75	0.07	0.08	0.07	0.06	0.09	0.06	0.07	0.09
150	0.08	0.10	0.09	0.08	0.07	0.12	0.08	0.07
Avg	0.08	0.08	0.08	0.07	0.09	0.09	0.08	0.08

¹Corrected for impurities.

²Days of growth after fertilization.

Table 28.- Total phosphorus contents of oven-dry Jaraguagrass roots¹ during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ²	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	kg/ha							
0	1.7	1.2	2.6	1.8	2.1	2.1	2.7	4.2
75	2.0	1.7	2.2	1.6	4.2	1.8	2.0	2.9
150	2.5	2.6	2.7	3.2	2.7	3.8	2.5	2.5
AVE	2.1	1.8	2.5	2.2	3.0	2.6	2.4	3.2

¹ Crowns included and corrected for impurities.

² Days of growth after fertilization.

Table 29.- Analysis of variance for yields of oven-dry jaraguagrass forage during the rainy season

Source of variation	Degrees of freedom	Mean squares	F
Main plots:			
N treatments	2	1,648,717	0.20
Blocks	2	817,081	
Main plot error	4	7,945,482	
Sub-plots:			
Days of growth	7	3,219,417	2.99*
Days X N treatments	14	3,811,405	3.54**
Sub-plot error	42	1,074,933	

* Significant at the 5% level.

** Significant at the 1% level.

Table 30.- Analysis of variance for nitrogen concentrations
in oven-dry jaraguagrass forage during the rainy
season

Source of variation	Degrees of freedom	Mean squares	F
Main plots:			
N treatments	2	0.00225	0.45
Blocks	2	0.00785	
Main plot error	4	0.00503	
Sub-plots:			
Days of growth	7	0.00437	2.93*
Days X N treatments	14	0.00369	2.47*
Sub-plots error	42	0.00149	

* Significant at the 5% level.

Table 31.- Analysis of variance for total nitrogen contents of oven-dry jaraguagrass forage during the rainy season

Source of variation	Degrees of freedom	Mean squares	F
Main plots:			
N treatments	2	4.5	0.05
Blocks	2	17.0	
Main plot error	4	93.5	
Sub-plots:			
Days of growth	7	46.2	2.70*
Days X N treatments	14	52.2	3.05**
Sub-plot error	42	17.1	

* Significant at the 5% level.

** Significant at the 1% level.

Table 32.- Analysis of variance for cellulose concentrations
in oven-dry jaraguagrass forage during the dry
season

Source of variation	Degrees of freedom	Mean squares	F
Replications	2	71.51	
N treatments, N	2	324.28	368.50**
Days of growth, D	2	111.01	126.14**
Interaction, ND	4	32.75	37.21**
Error	16	0.88	

** Significant at the 1% level.

Table 33.- Analysis of variance for in vitro cellulose digestion of oven-dry jaraguagrass forage during the dry season

Sources of variation	Degrees of freedom	Mean squares	F
Replication	2	14.94	
N treatments, N	2	198.03	30.27**
Days of growth, D	2	960.14	146.81**
Interaction, ND	4	28.25	4.32**
Error	16	6.54	

** Significant at the 1% level.

Table 34.- Potassium concentrations in oven-dry jaraguagrass forage during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ¹	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	%							
0	0.95	0.81	0.60	0.52	0.39	0.32	0.27	0.20
75	0.80	0.78	0.61	0.48	0.42	0.38	0.35	0.27
150	0.90	0.78	0.75	0.63	0.49	0.28	0.30	0.34
Avg	0.88	0.79	0.65	0.54	0.43	0.32	0.30	0.27

¹Days of growth after fertilization.

Table 35.- Calcium concentrations in oven-dry jaraguagrass forage during the dry season

N Applied	Harvest dates of first growth							
	Nov. 30 (48 days) ¹	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days)	Mar. 5 (143 days)
kg/ha	%							
0	0.75	0.66	0.44	0.52	0.59	0.70	0.61	0.75
75	0.94	0.76	0.41	0.66	0.89	0.52	0.82	0.62
150	1.21	0.80	0.46	0.44	0.46	0.55	0.61	0.55
AVG	0.96	0.74	0.43	0.54	0.64	0.59	0.68	0.64

¹ Days of growth after fertilization.

Table 36.- Magnesium concentrations in oven-dry jaraguagrass forage during the dry season

N Applied	Harvest dates of first growth						
	Nov. 30 (48 days) ¹	Dec. 14 (62 days)	Jan. 5 (84 days)	Jan. 13 (92 days)	Jan. 26 (105 days)	Feb. 9 (115 days)	Feb. 18 (128 days) Mar. 5 (143 days)
kg/ha	----- % -----						
0	0.33	0.23	0.17	0.19	0.23	0.17	0.19
75	0.37	0.40	0.28	0.28	0.26	0.27	0.31
150	0.57	0.48	0.32	0.24	0.27	0.37	0.37
Avg	0.42	0.37	0.25	0.23	0.25	0.23	0.29

¹ Days of growth after fertilization.

Table 37.- Phosphorus concentrations in oven-dry jaraguagrass forage regrowth during the rainy season

N Applied	Harvest dates of first growth							
	Nov. 30	Dec. 14	Jan. 5	Jan. 13	Jan. 26	Feb. 9	Feb. 18	Mar. 5
kg/ha	%							
0	0.10	0.09	0.09	0.10	0.10	0.10	0.09	0.09
75	0.10	0.10	0.10	0.11	0.10	0.09	0.09	0.10
150	0.09	0.10	0.10	0.10	0.09	0.10	0.10	0.08
Avg	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09

¹Days from initial harvest to August 19 were 262, 248, 226, 218, 205, 195, 182, and 167 days, respectively.

Table 38.- Potassium concentrations in oven-dry Jaraguagrass forage regrowth during the rainy season

N Applied	Harvest dates of first growth ¹							
	Nov. 30	Dec. 14	Jan. 5	Jan. 13	Jan. 26	Feb. 9	Feb. 18	Mar. 5
kg/ha	%							
0	0.61	0.54	0.55	0.59	0.45	0.50	0.53	0.47
75	0.55	0.45	0.47	0.48	0.55	0.54	0.52	0.64
150	0.46	0.48	0.54	0.68	0.38	0.35	0.47	0.37
Avg	0.54	0.49	0.52	0.58	0.46	0.46	0.50	0.49

¹ Days from initial harvest to August 19 were 262, 248, 226, 218, 205, 195, 182, and 167 days, respectively.

Table 39.- Calcium concentrations in oven-dry Jaraguagrass forage regrowth during the rainy season

N Applied	Harvest dates of first growth ¹							
	Nov. 30	Dec. 14	Jan. 5	Jan. 13	Jan. 26	Feb. 9	Feb. 18	Mar. 5
kg/ha	----- % -----							
0	0.63	0.52	0.51	0.54	0.63	0.54	0.56	0.58
75	0.75	0.62	0.60	0.65	0.58	0.45	0.65	0.63
150	0.70	0.66	0.56	0.56	0.56	0.56	0.52	0.56
Avg	0.69	0.60	0.55	0.58	0.59	0.51	0.57	0.59

¹ Days from initial harvest to August 19 were 262, 248, 226, 218, 205, 195, 182, and 167 days, respectively.

Table 40.- Magnesium concentrations in oven-dry Jaraguagrass forage regrowth during the rainy season

N Applied	Harvest dates of first growth ¹							
	Nov. 30	Dec. 14	Jan. 5	Jan. 13	Jan. 26	Feb. 9	Feb. 18	Mar. 5
kg/ha	----- % -----							
0	0.21	0.20	0.19	0.18	0.21	0.19	0.20	0.20
75	0.24	0.23	0.21	0.23	0.22	0.20	0.20	0.18
150	0.26	0.24	0.19	0.20	0.23	0.25	0.25	0.24
Avg	0.23	0.22	0.19	0.20	0.22	0.21	0.21	0.20

¹ Days from initial harvest to August 19 were 262, 248, 226, 218, 205, 195, 182, and 167 days, respectively.

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BIOGRAPHICAL SKETCH

Luis E. Tergas was born March 23, 1938, at Guaimaro, Cuba. In June 1956, he was graduated from Escuelas Pias High School in Camaguey, Cuba. In April 1959, he entered the Escuela Agricola Panamericana in Honduras. He was graduated with high honors in December 1961, and was awarded the Wilson Popenoe Scholarship to continue studies in Agricultural Sciences. He entered the University of Florida in September 1962 and received the degree of Bachelor of Science in Agriculture in December 1963. He was admitted to the Graduate School of the University of Florida and was granted an assistantship under the Caribbean Research Program. In April 1965 he received the degree of Master of Science in Agriculture. In May 1965 he was granted an assistantship by the Center for Tropical Agriculture to continue his work toward the degree of Doctor of Philosophy.

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This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor Philosophy.

August 1968



Dean, College of Agriculture

Dean, Graduate School

Supervisory Committee:



Chairman





